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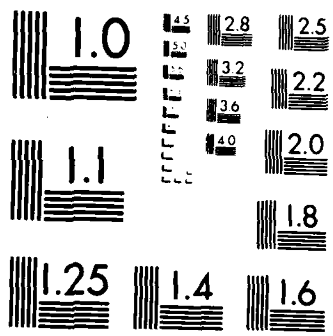

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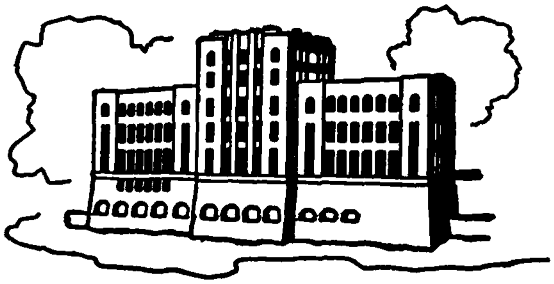
BED ARMORING PROCEDURES IN IALLUVIAL AND APPLICATION TO THE MISSOURI RIVER

by

M. F. Karim, F. M. Holly, and J. F. Kennedy

Sponsored by
U.S. Army Corps of Engineers
Omaha District, Nebraska
Contract No. DACW45-79-C-0020



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The Conceptual model of bed armoring employed in the IALLUVIAL numerical model for simulation of bed evolution in alluvial rivers has been critically assessed and refined. The approach involves use of the bed surface covered by immobile particles as a correction factor for reducing theoretical sediment transport capacity, reducing theoretical dune heights, and allocating energy losses between bed form resistance and surface roughness resistance. Computation of the armoring factor takes into account persistence in time, moving dune effects, and the stochastic nature of incipient particle motion. The report includes a review of current literature on armoring, describes the implementation of various armoring procedures in IALLUVIAL, and presents detailed results and analyses of all test performed, including several on the Missouri River between Omaha and Sioux City.

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EXECUTIVE SUMMARY

The IALLUVIAL computer program for prediction of long-term bed evolution in alluvial rivers was designed to take into account the effects of bed armoring on sediment transport and flow resistance. Recent studies of Missouri River bed evolution using IALLUVIAL have demonstrated the sensitivity of ultimate bed degradation to armoring.

The purpose of this study was to reassess critically the conceptual model of armoring used in IALLUVIAL, propose alternative methodologies having clearer physical bases, and test these alternatives on the Missouri River between Gavins Point Dam and Omaha.

The results of this study suggest that the fundamental armoring approach initially adopted should be retained; this approach involves use of a so-called armoring factor, defined as the fraction of bed surface covered by immobile particles, as a correction factor for reducing theoretical sediment transport capacity, reducing theoretical dune heights, and allocating energy losses between bed form resistance and surface roughness resistance. However the computation of the armoring factor itself has been considerably modified to take into account persistence in time, moving dune effects, and the stochastic nature of incipient particle motion. Two alternative procedures, in which an explicit treatment of armoring was abandoned in favor of use of thin surface and/or bed layers in which rapid bed material coarsening would simulate the effects of armoring, were tested and ultimately rejected.

This report includes a review of current literature on armoring, describes the details of implementation of various armoring procedures in IALLUVIAL, and presents detailed results and analysis of all tests performed.

ACKNOWLEDGEMENTS

The IALLUVIAL program has now been under development for several years, through the support of the Omaha District, U.S. Army Corps of Engineers; the National Science Foundation; and the Iowa State Water Resources Research Institute. The authors wish to express special thanks to Mr. Wayne Dorough of the Omaha District, and to Messrs. Al Harrison and Warren Mellema of the Missouri River Division, Corps of Engineers, for their interest in and contributions to both this study and its precursors. Grateful acknowledgement is also extended to the Graduate College of The University of Iowa for having provided a portion of the computer funds needed for the study's extensive computations.

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I. INTRODUCTION

The Missouri River between Gavins Point Dam and Omaha is currently undergoing complex changes in response to man-made constraints imposed upon it. The virtual elimination of upstream sediment supply by the trapping effect of Gavins Point Dam and other upstream multi-purpose developments, along with the maintenance of a nine-foot-deep navigation channel below Sioux City through channelization and bank stabilization, have caused the river to erode its bed rather severely. Since 1960 as much as eight feet of bed degradation has been observed near Sioux City. Such decreases in bed elevation, with their concomitant decreases in water level, are the source of serious concern for their engineering consequences (bank stability, structure stability, tributary headcutting, etc.) as well as their environmental effects (destruction of wildlife habitat, lowering of oxbow lake levels, increase in turbidity, etc.).

In view of the serious nature of these symptoms of the Missouri River's attempt to achieve a new equilibrium in response to the changes imposed upon it, there has been considerable interest in exploring the feasibility of proposed means of slowing the degradation, as well as in forecasting the future course of channel response.

The IALLUVIAL computer program was developed in response to this need for a means of forecasting future river response under both present conditions and proposed scenarios for engineering solutions to the degradation problem. IALLUVIAL is a deterministic, computer-based methodology for computation of long-term evolution of water surface level, bed level, and bed material composition in an assumed one-dimensional channel. Using Karim and Kennedy's (1982) Total Load Transport Model for simultaneous prediction of transport

capacity and bed friction factor, IALLUVIAL alternately solves the water flow energy equation and the sediment continuity equation in each of a series of incremental time steps. Bed elevation changes, as well as changes in bed material composition and surface armor layer, are thus estimated for imposed quasi-steady water discharge hydrographs, upstream and tributary sediment inflow hydrographs, and tributary inflow hydrographs.

The first application of IALLUVIAL was an attempt to reproduce the past twenty years of Missouri River bed evolution (Karim and Kennedy, 1982). Based on the encouraging results of that study, IALLUVIAL was generalized to allow for a more complete treatment of tributary inflows and fitted with procedures for the simulation of the effects of vertical nonhomogeneity of bed material, dredging, artificial cutoffs, bank erosion, and imposed width changes. A more detailed data set describing the Missouri River from Gavins Point Dam to Iowa's southern border was prepared, and the expanded program was used to predict the next twenty years of bed evolution under various scenarios. These scenarios included the continuation of present conditions, changes in Gavins Point Dam release schedules, artificial bed armoring, channel widening, sediment release from Gavins Point Dam, etc. The computations, reported in detail by Holly and Karim (1983), suggested that the worst of the degradation is probably over. Of more importance to the present study was the opportunity to identify several aspects of IALLUVIAL's methodology which were in need of reevaluation and possible reformulation. One of the more important of these methodologies was that used for simulating armoring, i.e. the tendency for larger bed material particles to form a protective coating over finer underlying material. This armoring may be a primary mechanism for ultimate degradation control in the Missouri.

The goal of the present study was to reassess critically the rather _ad hoc_ armoring formulation used in IALLUVIAL, and to propose and test alternative procedures having more sound physical bases. This report reviews the current literature on armoring in alluvial rivers; proposes several procedures for use in IALLUVIAL; describes their implementation in IALLUVIAL; reports the results of testing of these procedures on the Missouri River; and recommends the adoption of certain procedures in future use of IALLUVIAL. Appendices contain an IALLUVIAL listing as well as input format description and a sample input.

II. BED ARMORING PROCEDURES

A. Introductory Remarks

Armoring of the bed surface, along with general coarsening of the bed-material, are the principal mechanisms through which a degrading river bed downstream of a new dam attempts to achieve a new equilibrium condition. Representation of the bed armoring process in a computer-based mathematical model, like IALLUVIAL, therefore is a critical component on which depends the accuracy in prediction of future river bed evolution. The armoring process is a complex phenomenon which depends on several interdependent factors, e.g., size distribution of bed material and its variation in the vertical direction below the bed, intensity of flow discharge and sediment transport, the formation and movement of bed features like ripples and dunes, and the continual sorting and mixing of bed sediments as affected by these bed features. The armoring process as it begins and evolves during the gradual degradation process of an alluvial river bed is not well understood. Nevertheless, the existing knowledge in this area has been used to improve the present formulation of bed armoring in IALLUVIAL. The following sections present a literature review and descriptions of the previous and the proposed procedures of bed armoring incorporated into the program.

B. Literature Review

In more than three decades since the pioneering work of Harrison (1950), many investigators have studied the bed armoring process in alluvial rivers. Because of the complexity of the phenomenon, the progress has been painfully slow. The present state of knowledge in this area is summarized below by

brief descriptions of the works of Harrison (1950), Gessler (1967), Little and Mayer (1972), and Shen and Lu (1983).

1. Harrison's Analysis. The earliest investigation on bed armoring in alluvial channels was reported by Harrison (1950). He performed laboratory experiments with three different bed-material sizes to study the development of armoring in a degrading bed, and used Einstein's method to analyze his experimental data. Harrison's major conclusions, as summarized by Little and Mayer (1972), were:

"1. The accumulation of non-moving particles on the bed surface causes an increase in its effective roughness.

2. It has been found that a layer of non-moving particles, the thickness of one particle, is effective in preventing scour. It is felt that a complete layer of non-moving particles is not necessary in all cases.

3. Non-moving particles in a pavement arrange themselves in a characteristic "shingled" formation.

4. The Einstein relationship for the rate of transport predicts very well the limiting grain size, i.e., a size larger than that for which there is no transport. Einstein's function for the limiting size was $\Psi_* = 27$."

2. Gessler's Procedure. Gessler (1967) proposed a procedure to determine the size distribution of the armor coat on an alluvial bed. He argued that the incipient motion of grains is a probabilistic process, as opposed to the usual assumption of its deterministic character first suggested by Shields (1936). Assuming that the instantaneous bed shear stress fluctuates widely around its mean value in time, and that this Gaussian-distributed fluctuating bed shear stress is responsible for the stochastic nature of sediment motion, Gessler formulated an expression for the

probability that a grain of given size will remain a part of the top layer (armor coat). With the assumption that this probability depends on the magnitude of the mean bed shear stress, τ, relative to the critical shear of the sediment size fraction k, τ_{ck}, the probability of grain size k to remain as part of the top layer, q_k, is given as

$$q_k = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{(\tau_{ck}/\tau - 1)} \exp\left(-\frac{x^2}{2\sigma^2}\right) dx \qquad (1)$$

in which x is a dummy variable and σ is the standard deviation of the assumed Gaussian distribution of the bed shear stress fluctuations in time. The value of σ was determined as 0.57 by Gessler (1967) from a series of flume experiments in which he measured the grain size distribution of the eroded and the armor-coat materials. Equation (1) with σ = 0.57, along with the experimental points, is represented graphically in figure 1. With q_k calculated from Eq. (1) or figure 1, the frequency function for grain size interval k of the armor coat, P_{ak}, is obtained from

$$P_{ak} = \frac{q_k\, p_{ok}}{\sum_{k=1}^{m} q_k\, p_{ok}} \qquad (2)$$

where p_{ok} = frequency function (or fraction) of grain size interval k of the initial bed material; and m = total number of size fractions.

Gessler (1970) further suggested that the mean value of the probabilities for the armor-coat grains to stay, $\overline{q}$, may be utilized as a stability criterion of the armor coat:

$$\overline{q} = \sum_{k=1}^{m} q_k p_{ak} = \frac{\sum_{k=1}^{m} q_k^2\, p_{ok}}{\sum_{k=1}^{m} q_k p_{ok}} \qquad (3)$$

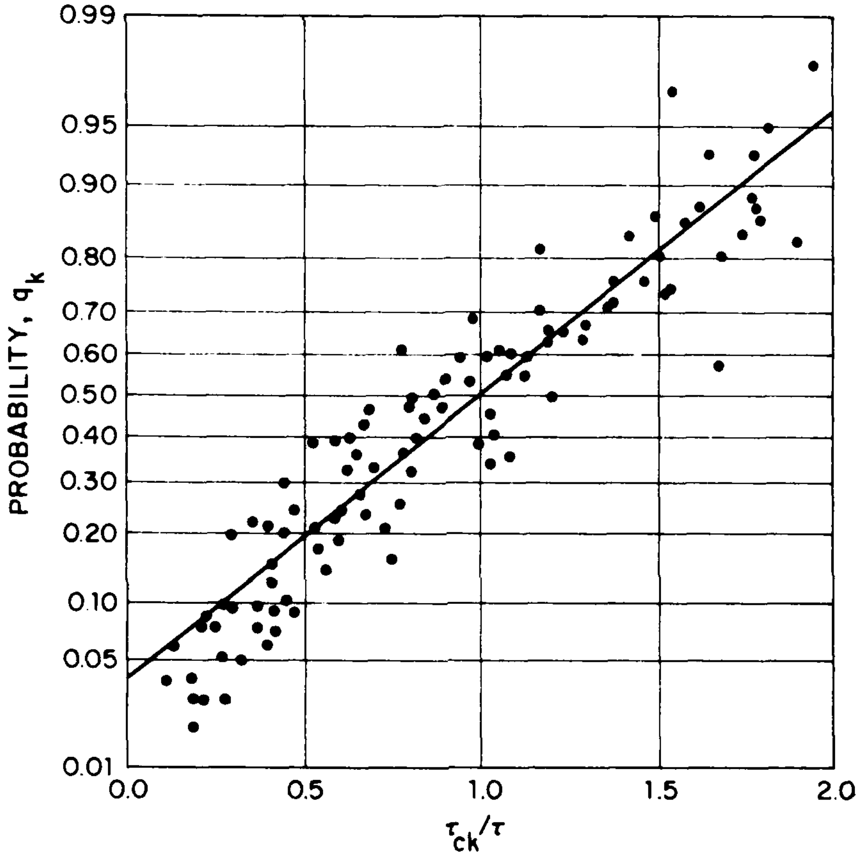


Figure 1. Probability of grains to stay (Gessler, 1967)

A value of $\overline{q} = 0.50$ was suggested as the critical value above which armor coat would be stable. For design criterion of stable irrigation canals, $\overline{q} = 0.65$ was recommended.

3. Little and Mayer's Method. Little and Mayer (1972) performed extensive laboratory experiments in a recirculating flume, 60 feet long and 1.97 feet wide, to study the effect of sediment gradation on channel armoring. They used in their experiments sands having log-normal distributions with median size D_{50} = 1.0 mm and six different gradation coefficients (geometric standard deviations) σ_g = 1.12, 1.50, 2.05, 2.50, 3.00, and 3.05. After virtual cessation of sediment discharge, the size distribution of the armored bed was measured for each run by surface sampling using purified bee's wax. From a least-squares analysis of the experimental results, an expression for the median size of the final armor coat, d_{ga}, was obtained:

$$\frac{d_{ga}}{d_{go} \cdot \sigma_{go}} = 0.908 \left[\frac{u_{*c}^3}{\nu(s-1)g}\right]^{0.353} \tag{4}$$

where d_{go} = median size of original bed; σ_{go} = gradation coefficient of the original bed; u_{*c} = critical shear velocity from Shields' diagram; ν = kinematic viscosity; s = specific gravity of sand particles; and g = gravitational constant. It may be noted that the expression within brackets on the right-hand side of Eq. (4) is the product of the Shields' parameter and the critical particle Reynolds number.

The geometric standard deviation of the armor coat, σ_{ga}, is calculated from

$$\frac{\sigma_{ga}}{\sigma_{go}} = 1.317 - 0.2485\, \sigma_{go} \tag{5}$$

In the formulation of Eq. (5) from measured data, sediment particles smaller than d_{ga} in the armor coat were excluded from analysis, because these particles were wedged between larger particles and, thus, did not contribute to the stability of the bed. It was suggested that the bed would be armored if d_{ga} computed from Eq. (4) is larger than d_{05} but less than d_{95}, where d_{05} and d_{95} are the particle sizes of the original bed for which 5 and 95 percent are finer, respectively.

In an analysis of their experimental data using Gessler's (1967) procedure, Little and Mayer (1972) noted that d_{ga}'s predicted by Gessler's method underestimated the corresponding measured values by as much as 29 percent; good agreement was, however, observed if Gessler's recommended values of Shields' parameter, and standard deviation of dimensionless shear stress, were modified from 0.047 and 0.57 to about 0.030 and 0.45, respectively.

In their experiments, Little and Mayer observed that dunes formed initially, and as they moved off and disappeared from the flume bed, armoring became apparent. Armoring of the surface had no significant effect on average bed shear stress, because the slight reduction (5%) in slope was compensated by a corresponding increase in flow depth. They further observed that after an armor coat had formed, a very low sediment transport rate continued for long periods of time, fed by local erosion of finer particles around larger ones. For runs with $\sigma_{go} \geq 2.0$, there was very little reduction in slope, with the armored bed degrading essentially parallel to the original bed slope; for $\sigma_{go} < 1.50$, there was little armoring, and for $\sigma_{go} = 1.12$, the bed was free of armoring under all flow conditions.

4. Shen and Lu's Analysis. The most recent analysis of bed armoring process is presented by Shen and Lu (1983). Their method is essentially an extension of Gessler's (1967) procedure, with modifications suggested for estimating the probability that grains of size interval k remain in the armor coat, q_k (given by Gessler (1967) in the form of Eq. (1) or figure 1). These modifications, as suggested by Shen and Lu, are:

(i) The upper limit of integration of the expression for q_k, Eq. (1), is changed by multiplying the critical shear stress for size fraction k, τ_{ck}, by the hiding factor, ξ, leading to a modified form of Eq. (1):

$$q_k = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\xi \frac{\tau_{ck}}{\tau} - 1} \exp\left(-\frac{x^2}{2\sigma^2}\right) dx \qquad (6)$$

The relation for hiding factor (ξ) was adapted from Einstein's (1950) analysis, using a fitting procedure based on Little and Mayer's (1972) experimental data, and on the basis of the argument that Einstein's original ξ-curve was grossly overestimated. Shen and Lu's proposed graphical relation for ξ as a function of D/x, in which D = grain size and x = characteristic grain size (a function of apparent roughness height and laminar sublayer thickness) is presented in figure 2a.

(ii) The value of τ_{ck} in Eq. (6) is calculated from a modified Shields' curve, given in figure 2b (Shen and Lu (1983)). The deviation (reduction) of the critical shear stress value from Shields' diagram, as seen in figure 2b, is caused as argued by Shen and Lu, by the greater exposure of larger particles to flow, due to their protrusion from the mean bed surface. It should be noted here that figure 2b gives the critical shear stress for incipient motion of the mixture of bed particles, using the 30% grain diameter

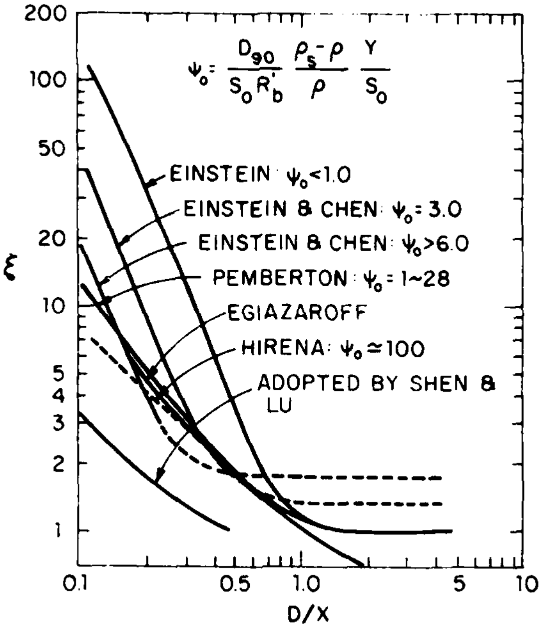


Figure 2a. Hiding factor of sediment particles in mixture (Shen and Lu, 1983)

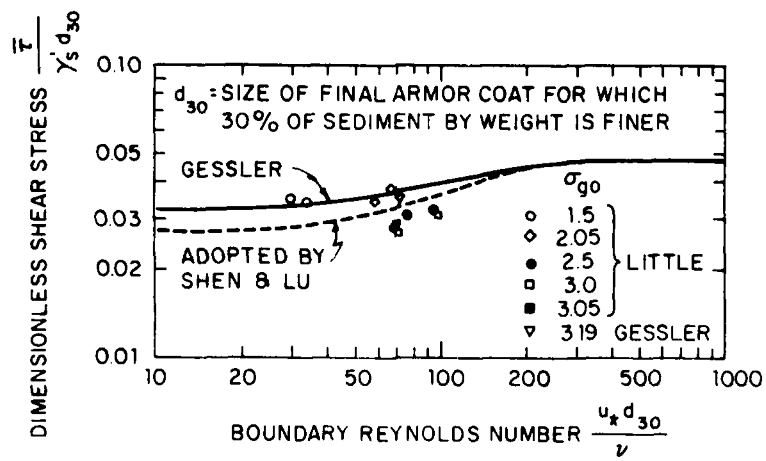


Figure 2b. Modified Shields' curve (Shen and Lu, 1983)

as the representative size of the mixture. Thus, according to Shen and Lu's procedure, the value of τ_{ck} is independent of the sediment size interval and is determined by the 30% size of the mixture; therefore, the differentiation in q_k for each size fraction is represented in Eq. (6) only through the hiding factor, ξ. Again, Shen and Lu's modified Shields' curve in figure 2b is heavily influenced by Little and Mayer's (1972) experimental data.

(iii) The constant value of σ = 0.57 (σ = standard deviation of the normally distributed bed shear stresses, Eqs. (1, 6) as used by Gessler (1967)) is modified and assumed to be a function of the gradation coefficient, σ_g, of the initial size distribution. The relation between σ and σ_g is expressed by Shen and Lu in the following tabular form (table 1):

Table 1

Relation between standard deviation of bed shear stress (σ) and gradation coefficient (σ_g) of initial size distribution [Shen and Lu (1983)]

σ_g	1.5	2.0	2.5	3.0	3.05	3.19
σ	0.35	0.35	0.35	0.40	0.41	0.45

To summarize, Shen and Lu's procedure determines the size distribution of the final armor coat from Gessler's (1967) relation, Eq. (2), in which the probability of staying, q_k, is calculated from Eq. (6) (modified Eq. (1)) using figures 2a and 2b and table 1 to estimate ξ, τ_{ck}, and σ, respectively.

From a statistical analysis of experimental data of Little and Mayer (1972) and Gessler (1967) and of the field data of Lane and Carlson (1953), with a total of 14 data points, Shen and Lu (1983) proposed the following regression equations to predict D_{50}, D_{30}, and D_{84} of the final armor coat:

$$\frac{D_{50}}{D_{50i}} = 0.853 \left(\frac{\tau}{\tau_c}\right)^{0.456} (\sigma_g)^{0.885} \qquad (7)$$

$$\frac{D_{30}}{D_{30i}} = 0.658 \left(\frac{\tau}{\tau_c}\right)^{-0.404} (\sigma_g)^{2.290} \qquad (8)$$

$$\frac{D_{84}}{D_{84i}} = 1.189 \left(\frac{\tau}{\tau_c}\right)^{0.710} (\sigma_g)^{-0.200} \qquad (9)$$

in which τ_c = critical shear stress corresponding to D_{50}; D_{50}, D_{30}, D_{84} = sediment sizes for which 50%, 30% and 84% are finer in the armor coat, respectively; and D_{50i}, D_{30i}, D_{84i} = the corresponding values of D_{50}, D_{30}, and D_{84} of the initial size distribution.

5. Discussion. From the brief descriptions in the preceeding sections, it is apparent that the works of Harrison (1950), Gessler (1967), Little and Mayer (1972), and Shen and Lu (1983) presented significant contributions toward an understanding of the bed armoring process. Nevertheless, present knowledge on armoring of alluvial beds is not satisfactory, particularly from the point of view of dynamic simulation of temporal evolution of armoring on a degrading river bed. Gessler and Little and Mayer, for example, developed relations to predict the size distribution of the final armor coat after sediment transport practically stopped, but the evolution of bed armoring with progressing bed degradation was not investigated. Shen and Lu's procedure, which essentially adapted Gessler's method to Little and Mayer's experimental

data, suffers from the same limitation. An additional shortcoming of these investigations is that they were limited to flow conditions corresponding only to a plane bed. Very little is known about the role of armoring on an active bed with continuous formation and propagation of ripples and dunes.

In view of the above discussion, the need for further research in the following two areas can be hardly overemphasized: (i) the dynamic relation among the amount of degradation, flow variables, and the extent of armoring from its initiation to the final stage; and (ii) the mechanism of sorting among different size fractions within the bed forms (ripples and dunes) and their effects on bed armoring. The following sections attempt to formulate these two features of the bed armoring process for their incorporation into the IALLUVIAL program with the realization that this is a first step which will need continuous refinement as more knowledge is gained in this area.

C. Armoring Procedures in IALLUVIAL

The present code of IALLUVIAL includes several alternative procedures to account for bed armoring in alluvial channels; these procedures are described in the following sections. Section II.C.1 presents the method which was the only armoring procedure included in IALLUVIAL before this study. The remaining sections describe the new armoring procedures included in the new version of IALLUVIAL.

1. Degradation and Armoring on a Plane Bed. For flow conditions which produce a nearly flat bed in rivers, gradual degradation (downstream of a dam, for example) of a bed containing a significant amounts of coarse sediments which could not be moved by the flow will lead to rapid armoring of the bed surface. The extent of armoring in such a case can be determined by relating

the depth of degradation to the corresponding volume of non-moving sediment size fractions and then converting the volume of accumulated sediments into an areal distribution by assuming some thickness of the top layer. Even though the experimental works of Gessler (1967) and Little and Mayer (1972) and field observations indicate that the armor coat contains sediments of all size fractions of the original bed material, it is assumed in the present analysis that as the armoring develops with increasing bed degradation, the bed surface is segregated into two parts: the armor coat, and the part of the bed containing the movable size fractions, as depicted in figure 3. It is assumed that the parameter of interest is the fraction of the bed covered by the non-moving armoring particles, because the finer particles in between the larger ones do not contribute to the stability of the bed and will become part of the sediment transport at one time or another, even though some of them may be sheltered by the armoring particles. From this point of view, determination of the complete size distribution of an armor coat is not necessary and is not attempted in this study. Instead, the fraction of bed surface covered by non-moving particles at any given time is used as a measure of the extent of armoring on a degrading bed.

For determining the fraction of the bed surface covered by immobile particles at a given time, $A_f(t)$, it is assumed that there are a total of m size fractions, of which fractions ℓ through m ($\ell < m$) cannot be transported by the flow and accumulate on the surface in a one-diameter-thick top layer. The total volume of these accumulating particles per unit bed area after time t is

$$V(t) = (1-p)\, d_s(t) \sum_{k=\ell}^{m} p_k \tag{10}$$

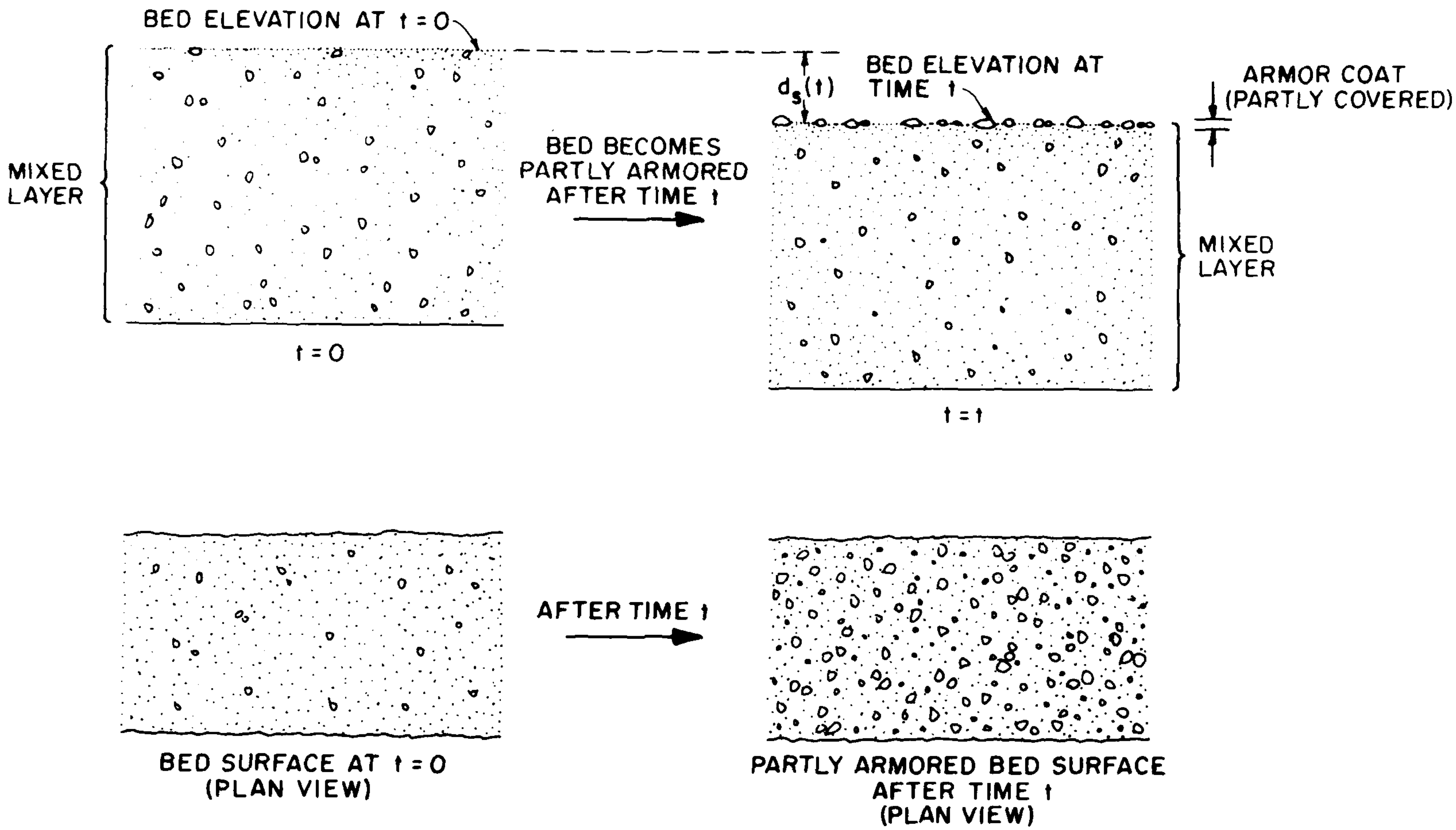


Figure 3. Schematic representation of armoring on a plane bed

where p = porosity of sediment bed material; $d_s(t)$ = cumulative depth of degradation after time t; and p_k = fraction of sediment in size interval k. Assuming that the shape of particles is circular ellipsoid with a shape factor f_s (ratio of the smallest principal axis to the square root of the product of the other two), the volume of a particle of fraction k with diameter of its major axis equal to D_{mk} is

$$V_k = \frac{\pi}{6} \cdot f_s \cdot D_{mk}^3 \tag{11}$$

and the number of armoring particles per unit bed area after time t is then

$$N(t) = \sum_{k=\ell}^{m} V(t,k)/V_k = \frac{(1-p)d_s(t)}{\frac{\pi}{6} \cdot f_s} \sum_{k=\ell}^{m} \frac{p_k}{D_{mk}^3} \tag{12}$$

in which $V(t,k)$ = value of $V(t)$ for grain size interval k. The surface area covered by the armoring particles per unit bed area after time t, $A_f(t)$, may then be expressed as

$$A_f(t) = N(t) \times \text{largest projected area of each particle } (= \frac{\pi}{4} D_{mk}^2)$$

$$= \frac{(1-p)\ d_s(t)}{\frac{\pi}{6} \cdot f_s} \cdot \frac{\pi}{4} \sum_{k=\ell}^{m} \frac{p_k}{D_{mk}^3} D_{mk}^2$$

$$= \frac{3}{2} \cdot \frac{(1-p)\ d_s(t)}{f_s} \sum_{k=\ell}^{m} \frac{p_k}{D_{mk}} \tag{13}$$

Writing V_k (Eq. 11) in terms of an equivalent spherical particle of diameter D_k,

$$V_k = \frac{\pi}{6} \cdot f_s \cdot D_{mk}^3 = \frac{\pi}{6} \cdot D_k^3$$

yields the following expression for D_{mk} in terms of D_k:

$$D_{mk} = \frac{1}{f_s^{1/3}} D_k$$

which is substituted into Eq. (13) to give

$$A_f(t) = \frac{3}{2} \cdot \frac{(1-p)d_s(t)}{f_s^{2/3}} \sum_{k=\ell}^{m} \frac{p_k}{D_k} \tag{14}$$

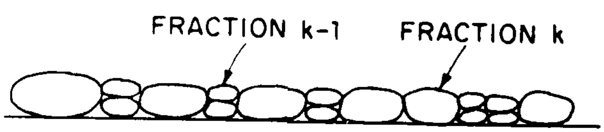
Assuming a shape factor $f_s = 0.70$, Eq. (14) is written as

$$A_f(t) = C_A\ (1-p)\ d_s(t) \sum_{k=\ell}^{m} \frac{p_k}{D_k} \tag{15}$$

in which $C_A = 1.902$.

The derivation of Eq. (15) assumes that the armor coat is one-diameter thick with the following idealized arrangement:

However, if the arrangement of armoring particles with two fractions (both non-moving), for example, is



the armoring coefficient C_A in Eq. (15) then will not be constant but different for each fraction, i.e.,

$$\begin{aligned} C_A &= 1.902 \text{ for fraction } k \\ &\simeq 1.902/2 \text{ for fraction } k\text{-}1 \end{aligned}$$

If some particles lie on their minor axis with major axes perpendicular to bed, the value of C_A will be further reduced. Thus, in general, C_A will be a function of each fraction and its particular arrangement in the armoring layer.

Equation (15) with $C_A = 0.50$ and $\ell = 7$ (with m = 8, this implies that the last two size fractions, sediment size > 6.76 mm, were always immobile and part of the armor coat) was utilized to account for bed armoring in the previous version of IALLUVIAL as applied in Missouri River studies to date. Three shortcomings of Eq. (15) are immediately apparent: (i) C_A is assumed constant in time for each size fraction; (ii) a fixed number of size fractions is always responsible for armoring; and (iii) the possibility of a particular size fraction being part of the armor coat in some time intervals and not at other times is not included. These shortcomings are in addition to the fact that Eq. (15) is strictly valid only for a plane bed.

The first step in removing these shortcomings is to extend the formulation of Eq. (15) to a more general case in which the dependence of A_f and C_A on grain size fraction and time is included:

$$A_f(t,k) = A_f(t-1,k) + C_A(t,k)\cdot(1-p)\ \Delta d_s(t)\ \frac{p_k}{D_k}$$

$$A_f(t,k) = 0;\ k < \ell(t) \tag{16}$$

$$A_f(t) = \sum_{k=\ell(t)}^{m} A_f(t,k)$$

in which $A_f(t,k)$ = fraction of bed area covered by grain size interval k at time t; $C_A(t,k)$ = value of coefficient C_A (Eq. 15) at time t for size fraction k; $\Delta d_s(t)$ = incremental depth of degradation during current time interval; and $\ell(t)$ = lowest grain size interval which is immobile (determined from Shields' criterion) and forms the armor coat at time t. Eq. (15) is a special case of Eq. (16) for $C_A(t,k) = C_A$ = constant and $\ell(t) = \ell$ = constant. The effects of the stochastic nature of sediment motion, and the effects of formation and propagation of dunes, are considered in the context of estimating the armoring coefficient C_A (t,k) for each sediment size fraction as a function of flow variables at a given time in the following sections.

The procedure followed in this study consists of formulating correction factors due to these effects (stochastic sediment motion and dune movement) to reduce the value of $C_A(t,k)$ in Eq. (16) from its maximum values of 1.902 for a plane bed.

<u>2. Stochastic Nature of Sediment Motion.</u> Shields' diagram is universally used to determine the critical bed shear stress above which sediment motion takes place. It has long been recognized, however, that this deterministic way of calculating a definite cut-off point needs to be replaced or supplemented by a procedure to account for the stochastic nature of sediment motion. Such a procedure is proposed by Gessler (1967) who suggested that incipient motion of grains is probabilistic and follows a Gaussian distribution, with the probability of motion being 50% when bed shear stress

equals critical stress given by Shields' relation. His analysis has been described in Section II.B.1. The probability of grains remaining on the bed (which is the complement of the probability of motion), q_k, as proposed by Gessler (1967), is given by Eq. (1) or figure 1 (Section II.B.1). The usual assumption is that $q_k = 1$ if $\tau_{ck}/\tau \geq 1$. Instead, figure 1 suggests that $q_k = 0.5$ for $\tau_{ck}/\tau = 1$ and approaches unity for τ_{ck}/τ greater than 3. This implies that larger grains are just more likely to stay, as opposed to assigning an equal probability of (100%) that all fractions greater than the critical size stay. This stochastic nature of sediment motion is accounted for indirectly by using q_k as a correction factor applied to C_A:

$$C_A(t,k) = 1.902\ q_k \tag{17}$$

It is perhaps more appropriate to consider q_k as a correction to p_k, the fraction of bed material in size interval k (Eq. 16), i.e. the availability of sediments to remain on the bed and form an armor coat is increased for larger sizes; because of the form of Eq. (16), this interpretation is mathematically equivalent to the formulation in Eq. (17).

3. Effect of Bed Forms on Armoring. An active river bed with continuous formation and propagation of dunes and ripples is less likely than a plane bed to be covered with a top layer of immobile particles forming an armor coat. Instead of staying and accumulating on the bed surface as for a plane bed, grains of different sizes within a subsurface layer (mixed layer) will be continuously mixed, the coarser sediments tending to be deposited (or even transported slowly depending on the flow intensity) close to the bottom or trough of a dune, as illustrated in figure 4. As the dune moves downstream,

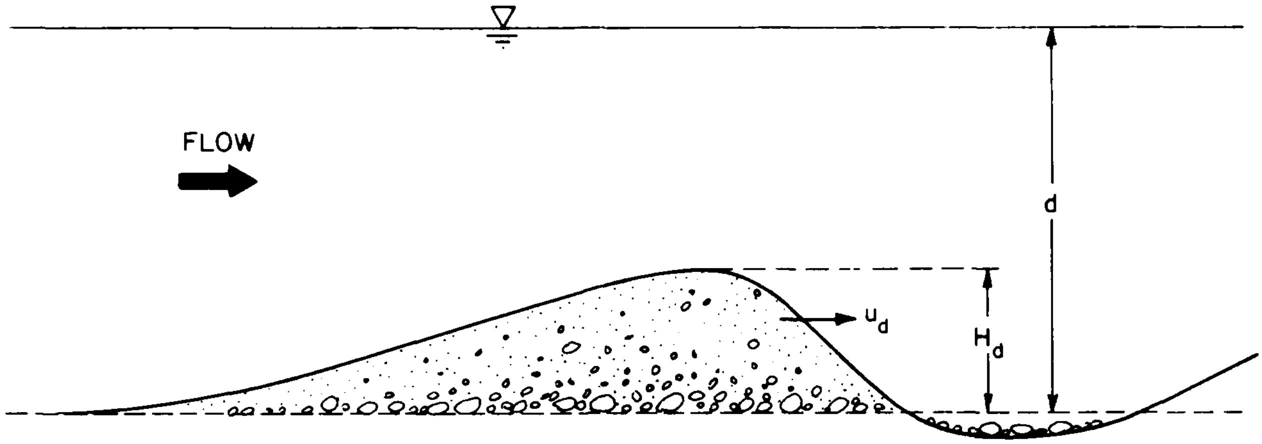


Figure 4. Schematic respresentation of sediment size distribution within a dune

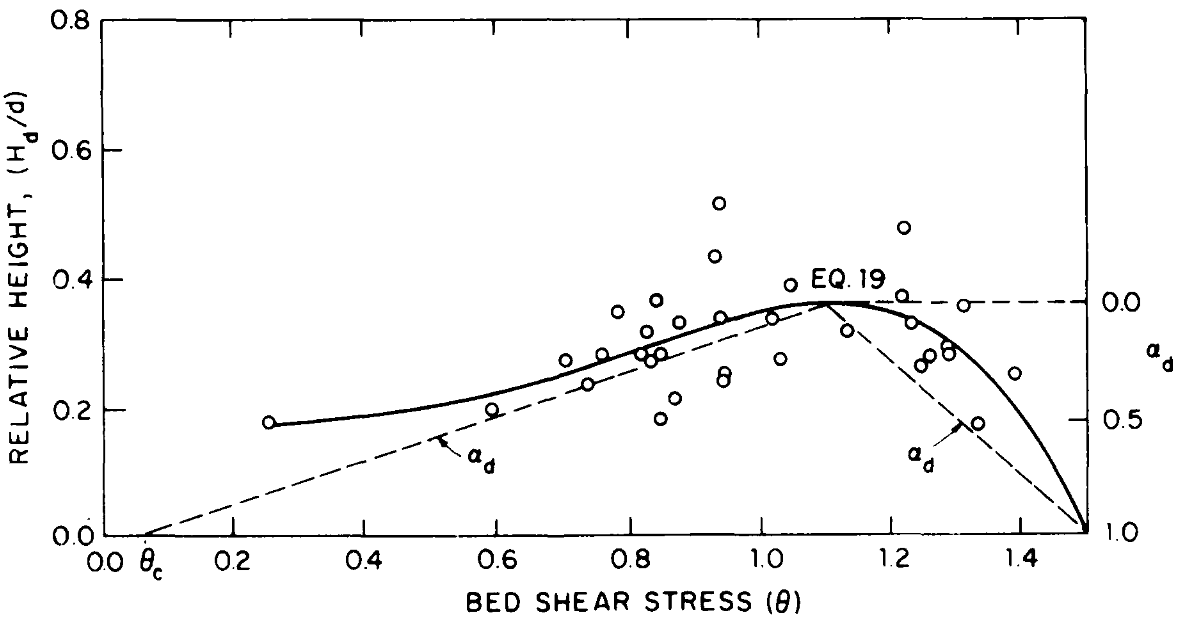


Figure 5. Relative dune height as a function of nondimensional bed shear stress (Allen, 1978) and a relation for α_d

the coarser particles at the bottom may be temporarily exposed to flow and transported as bed load before being redeposited again in the trough, or overlain by finer grains of the advancing dune immediately following from upstream. A vertical gradation in sediment sizes, with coarsest fractions at the bottom of the dune, is also likely to develop. A formulation of this rather complicated segregation process among different grain sizes within a dune is not available at present.

The present analysis is limited to development of a heuristic formulation of the reduction in the quantity of coarser sediments accumulating on bed surface due to the presence of dunes. It is assumed that this reduction can be accomplished by reducing the coefficient $C_A(t,k)$ in Eq. (17) from its maximum value of 1.902 q_k, for a plane bed, by multiplying C_A by a correction factor, α_d, as follows:

$$C_A\,(t,k) = 1.902\, q_k\, \alpha_d \tag{18}$$

in which α_d = correction factor for C_A due to the presence of dunes, varying between 0 and 1. $\alpha_d = 1$ corresponds to a plane bed, and $\alpha_d = 0$ implies complete segregation of materials within a dune, as depicted in figure 4 in which coarser sediments filter down to the dune bottom. It is further assumed that α_d is a function only of relative dune height, H_d/d (H_d = dune height; d = flow depth); This means that $\alpha_d = 1$ for $H_d/d = 0$ (plane bed); and $\alpha_d = 0$ for the maximum value of H_d/d, i.e., no armoring is possible in a fully active dune bed. In general, α_d is a function of dune height, dune velocity, and flow and sediment characteristics which determine the internal grain size distribution of dunes. It is assumed herein that α_d is an inverse function of relative dune height, H_d/d, as described below.

Allen (1978) developed the following relation for relative dune height,

$$H_d/d = b_0 + b_1 \left(\frac{\theta}{3}\right) + b_2 \left(\frac{\theta}{3}\right)^2 + b_3 \left(\frac{\theta}{3}\right)^3 + b_4 \left(\frac{\theta}{3}\right)^4 ; \; 0.25 < \theta < 1.5 \qquad (19)$$

where θ = nondimensional bed-shear stress = $\tau_0/[\rho(s-1)gD_{50}]$; τ_0 = bed-shear stress = ρgdS; b_0 = 0.079865; b_1 = 2.23897; b_2 = -18.1264; b_3 = 70.9001; and b_4 = -88.3293. Eq. (19) is depicted in figure 5. Using the conceptual model described in the previous paragraph, a linear relation between α_d and H_d/d (through θ) is assumed as shown by the dotted line in figure 5, which may be expressed as:

$$\begin{aligned}
\alpha_d &= 1.0 && ; \quad 0 < \theta_c \\
\alpha_d &= \frac{1.10-\theta}{1.10-\theta_c} && ; \quad \theta_c < \theta < 1.10 \\
\alpha_d &= \frac{\theta-1.10}{1.50-1.10} && ; \quad 1.10 < \theta < 1.50 \qquad (20) \\
\alpha_d &= 1.0 && ; \quad \theta > 1.50
\end{aligned}$$

in which θ_c = critical value of θ at incipient sediment motion, obtained from Shields' diagram. The limitation of this formulation for α_d, Eq. (20) or figure 5, is recognized; future refinements or modifications of the present formulation may be necessary as better knowledge becomes available about the development, and vertical distribution, of grain size composition within bed forms.

4. Effect of armoring on sediment discharge, friction factor and mixed layer. Armoring of the bed surface tends to reduce the sediment-transport capacity of flow, change the roughness characteristics of the bed, and diminish the average dune height or mixed-layer thickness which represents the zone of mixing of different bed-material grain sizes. These interdependencies are too complicated for a rigorous formulation, and are, therefore, approximated by the following relations in both the previous and present versions of IALLUVIAL:

$$q_{sa} = q_s \ (1 - C_1 A_f(t)) \tag{21}$$

$$f = f_m \ (1 - C_2 A_f(t)) + f_a C_2 A_f(t) \tag{22}$$

$$T_m = \frac{1}{2} H_d (1 - C_3 A_f(t)) \tag{23}$$

in which q_{sa}, q_s = sediment discharge/unit width over the armored bed, with and without armoring, respectively; f = composite friction factor of an armored bed; f_m, f_a = friction factor of the movable part and the armored part of the bed, respectively; T_m = mixed-layer thickness; and C_1, C_2, C_3 = calibration coefficients varying between 0 and 1. Variables q_s and f_m are obtained from simultaneous solution of the sediment-discharge and friction-factor relations, e.g., Eqs. (1) and (2) given in Section II.A of the report by Karim and Kennedy (1982). Any rigid-bed friction-factor relation, e.g., Colebrook-White, may be used to calculate f_a. Calibration coefficients, C_1, C_2, and C_3 have been assigned values of unity in the present analysis.

Bed armoring and its effects, as described by Eqs. (16) through (23), constitute the basic armoring procedure included in the present version of IALLUVIAL. In the course of the present investigation, however, two additional/alternative procedures were developed to account for the armoring of the bed surface in an indirect way. These are described in the next two sections.

5. Bed-Layer Procedure. In contrast to the approach described in the preceeding sections, this procedure does not divide the bed surface into two parts, the armored (no transport) and unarmored (erodible) bed. This procedure assumes that a top layer coarsens faster than the mixed layer (whose thickness is comparable to the average dune height), and this increased coarsening of the top layer, if incorporated through D_{50} into the sediment discharge and friction factor calculations, should yield the same effect as consideration of an armor coat protecting the underlying finer materials in the mixed layer. This concept was first utilized by Park and Jain (1983), and is presently under further development at the Iowa Institute of Hydraulic Research. The procedure described below is based on this concept, but differs considerably from Park and Jain's analysis in its detailed formulation.

A bed layer of thickness y_b given by (Karim and Kennedy, 1981)

$$y_b = D_{50} \cdot \frac{u_*}{u_{*c}} \tag{24}$$

is assumed at the top of the mixed layer (whose thickness is equal to average dune height), as illustrated in figure 6. In Eq. (24), D_{50} = median size of the bed layer; u_* = bed shear velocity; and u_{*c} = critical shear velocity obtained from Shields' diagram. In the case of degradation, materials will be

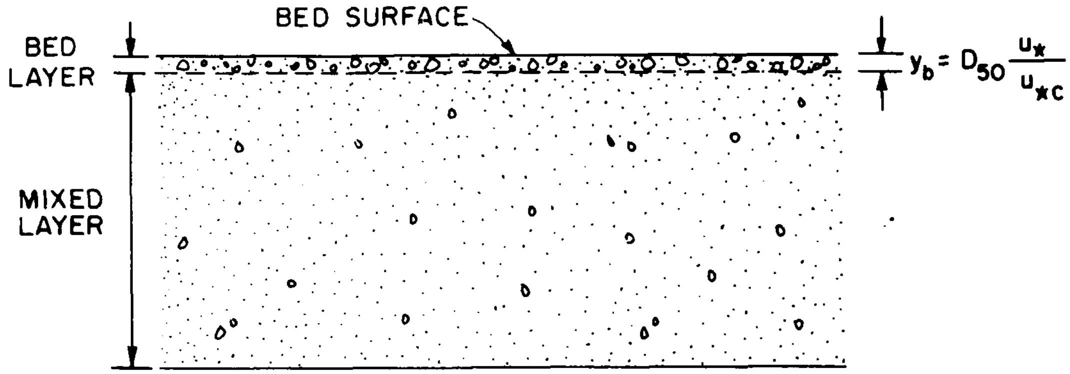


Figure 6. Schematic representation of bed-layer procedure

first scoured from the bed layer, and if the transport capacity for a particular grain size is still not satisfied, the remaining materials of that size fraction will be taken out of the mixed layer. At the end of the current time period, the composition of the bed layer is updated by assuming that the volume of sediments taken out of the bed layer is filled in by materials from the underlying mixed layer. In the case of aggradation, the bed-layer composition is updated considering the volume and size distribution of sediments deposited above it; if the thickness of deposited sediment is equal to or more than that of the bed layer given by Eq. (24), the composition of the bed layer will be the same as that of the deposited sediments. The size distribution of the mixed layer is updated continuously taking into account degradation or deposition in each time interval; the volume of the bed layer, whose thickness is negligible compared to the mixed layer, is ignored in this calculation.

It is important to note that the bed layer, as described above and depicted in figure 6, does not act as an armor coat of immobile sediments. Neither is the separate existence of an armor coat considered, i.e., the armoring factor $A_f(t)$ is always equal to zero in Eqs. (21), (22), and (23) which explicitly take into account the effect of armoring on sediment discharge, friction factor and mixed-layer thickness. The median size of the bed layer material is used in all sediment discharge, friction factor and mixed-layer thickness calculations. Because the bed layer, in general, will coarsen faster in a degrading bed than the mixed layer, this procedure is presumed to account indirectly for the effects of armoring.

The prediction accuracy and validity of this procedure are examined in Chapter IV.

6. Surface-Layer Procedure. This procedure retains the basic features of the armoring calculations described in Sections II.C.1 through II.C.4, with the following two differences: (i) the median size, D_{50}, used in the sediment discharge, friction factor and mixed-layer thickness calculations is obtained from a weighted average (by surface area exposed) of the mixed-layer and armor-coat sediment sizes; and (ii) the effects of armoring on sediment discharge, friction factor and mixed-layer thickness are not considered, the armoring factor $A_f(t)$ in Eqs. (21), (22), and (23) being always equal to zero.

The median size of the surface layer, denoted by D_{50s}, is calculated from

$$D_{50s} = D_{50m} (1 - A_f(t)) + \sum_{k=\ell(t)}^{m} A_f (t,k) \cdot D_k \tag{25}$$

where D_{50m} = median sediment size of the mixed layer. It is seen from Eq. (25) that D_{50s} will be, in general, equal to or more than D_{50m}, since it includes contributions from armoring sediment sizes. It is assumed in this procedure that the increased value of D_{50s} will indirectly account for the effects of armoring on sediment discharge, friction factor and mixed-layer thickness.

Effectiveness of this procedure will be examined from its application to the Missouri River in Chapter IV.

III. IALLUVIAL COMPUTER PROGRAM

A. Description of the Program

The program IALLUVIAL has been reorganized and considerably extended recently to incorporate additional features, e.g., dynamic storage allocation to optimize memory requirements, variation of bed material composition with depth, and sediment inputs from tributaries and bank erosion. For a complete description of the program and these features, reference is made to IIHR (Iowa Institute of Hydraulic Research) Report No. 250, Addendum to IIHR Report No. 250, and IIHR Report No. 267. The present version of IALLUVIAL consists of MAIN and 17 subroutines: SMAIN, INFLOW, SEDBED, START, CHANGE, DREDGE, WATPRO, RESIS1, TRASF, SECPRO, SLOAD, ARMOR, HYSORT, VSORT, SHIELD, TRIB, and ERROR1. An abbreviated block diagram of the program, with brief descriptions of the function of each subroutine and the flow of information among them, is shown in figure 7. Modifications and additions to the computer code under the present study are briefly described in the next section.

B. Modifications and Additions

Major modifications/additions were incorporated into the subroutine ARMOR to include the additional armoring procedures described in Chapter II. In addition, this includes the option to use a particular armoring procedure, the option to specify initial armoring of bed, and the option for calculating armoring fractions as a function of time and flow conditions or for specifying a fixed number of sediment size fractions to form an armor coat. The subroutine INFLOW was added to allow more general specification of water and sediment inflows and downstream boundary conditions. An additional feature of INFLOW is that it permits linear interpolation for estimating input values at

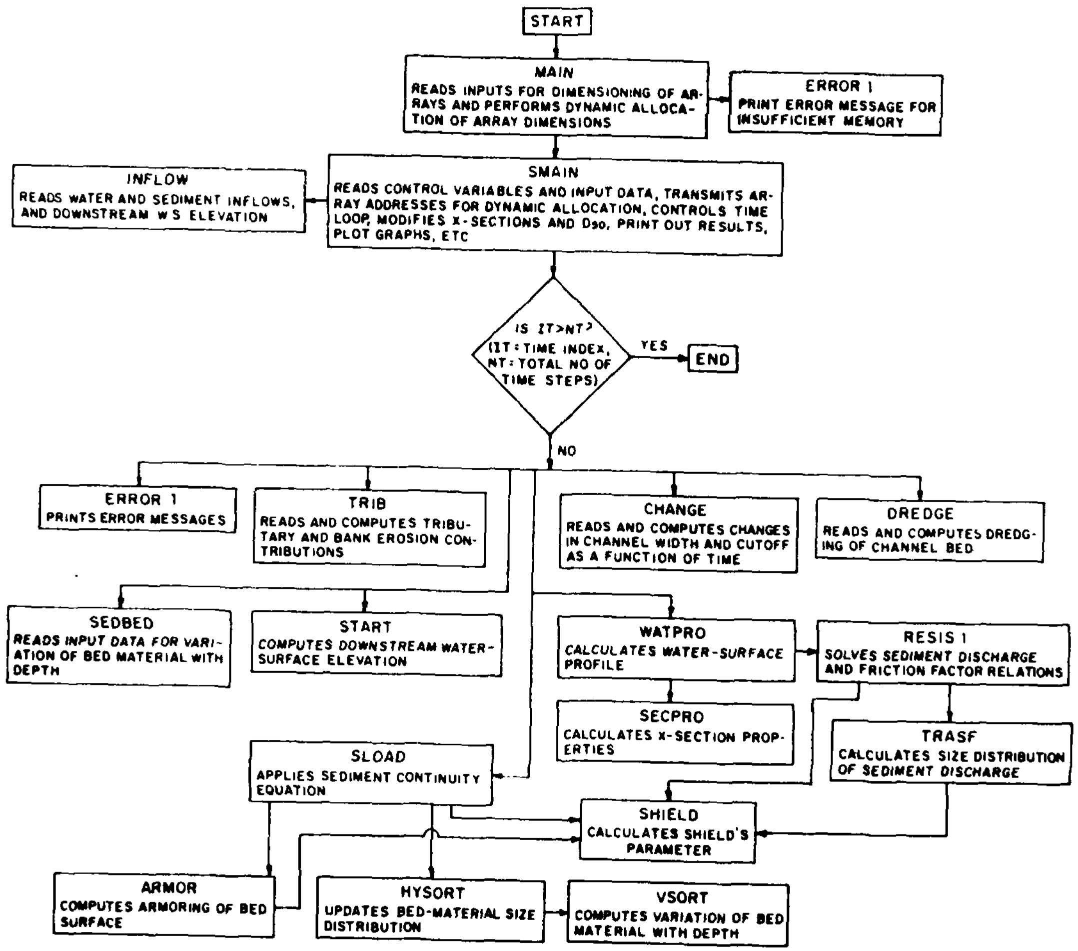


Figure 7. Summary block diagram of IALLUVIAL

intermediate time steps from two successive read-in values at the bounding time points. Appropriate instructions have been included to write and store major results from the output of the program in disc files, which can be retrieved later for graphical analysis or other purposes.

A minor but important change has been made in subroutine HYSORT to modify the procedure for updating the bed-material composition. With reference to Section II.F of IIHR Report No. 250, Eq. (13a) was used for updating bed-material size distribution in the first upstream subreach (immediately downstream of dam), and Eq. (13) was used in the remaining subreaches. This differential treatment was based on the argument that the sorting process near the dam was different due to the absence of bed forms, thus leading to faster coarsening compared to the other subreaches in which beds are dominated by the formation and propagation of dunes. This argument appears to be less justifiable in view of the present analysis of armoring procedures described in Chapter II. It is reasonable to remove this distinction in the sorting procedure and let the armoring procedure, which accounts for the effect of bed forms on mixing process in active layer through bed armoring, take care of the difference, if any. Based on this consideration, the computer code has been modified so that Eq. (13) (of IIHR Report No. 250) is employed consistently to update the bed-material size distribution of a degrading bed in all subreaches. This means that the bottom of the mixed layer of a degrading bed (refer to figure 2 of IIHR Report No. 250) always moves downward, i.e., as the bed degrades, fresh materials entering the mixed layer always have the distribution of the parent bed materials (in contrast, use of Eq. (13a) means that the entering materials may be coarser than the parent materials under certain conditions). The significance of this change on simulation results is discussed in Chapter IV.

IV. APPLICATION TO THE MISSOURI RIVER

A. Introductory Remarks

The objective of this chapter is to present an input data set representing the 195-mile reach of the Missouri River between Gavins Point Dam (GPD) and Omaha, with geometrical and bed-sediment characteristics prevailing at the time of the dam closure, 1956, and to present predicted changes in bed and water surface elevations obtained from IALLUVIAL for the 20-year period (1956-76) since closure of the dam. For a description of the study reach, reference is made to IIHR Report No. 250. A map of the Missouri River basin and schematic representation of the study reach are shown in figures 8 and 9. The study reach was represented by idealized rectangular-chann l sections and bed-sediment characteristics, and a two-stage water discharge hydrograph. These input data are described in the next section, followed by the presentation and discussion of simulation results in the remaining sections of this chapter.

B. Description of Input Data

The basic input data used in the simulation runs is the same as that described for Case IV.B in figures XII-1 through XII-5 of the Addendum to IIHR Report No. 250. These are presented in the following sections for ready reference.

1. Water Discharge Hydrograph. The upstream water discharge from Gavins Point Dam is approximated by a two-step hydrograph: 36,000 cfs during the navigation season (April to November) and 15,000 cfs during the non-navigation season (December to March). Eight tributaries (James, Vermillion, Big Sioux,

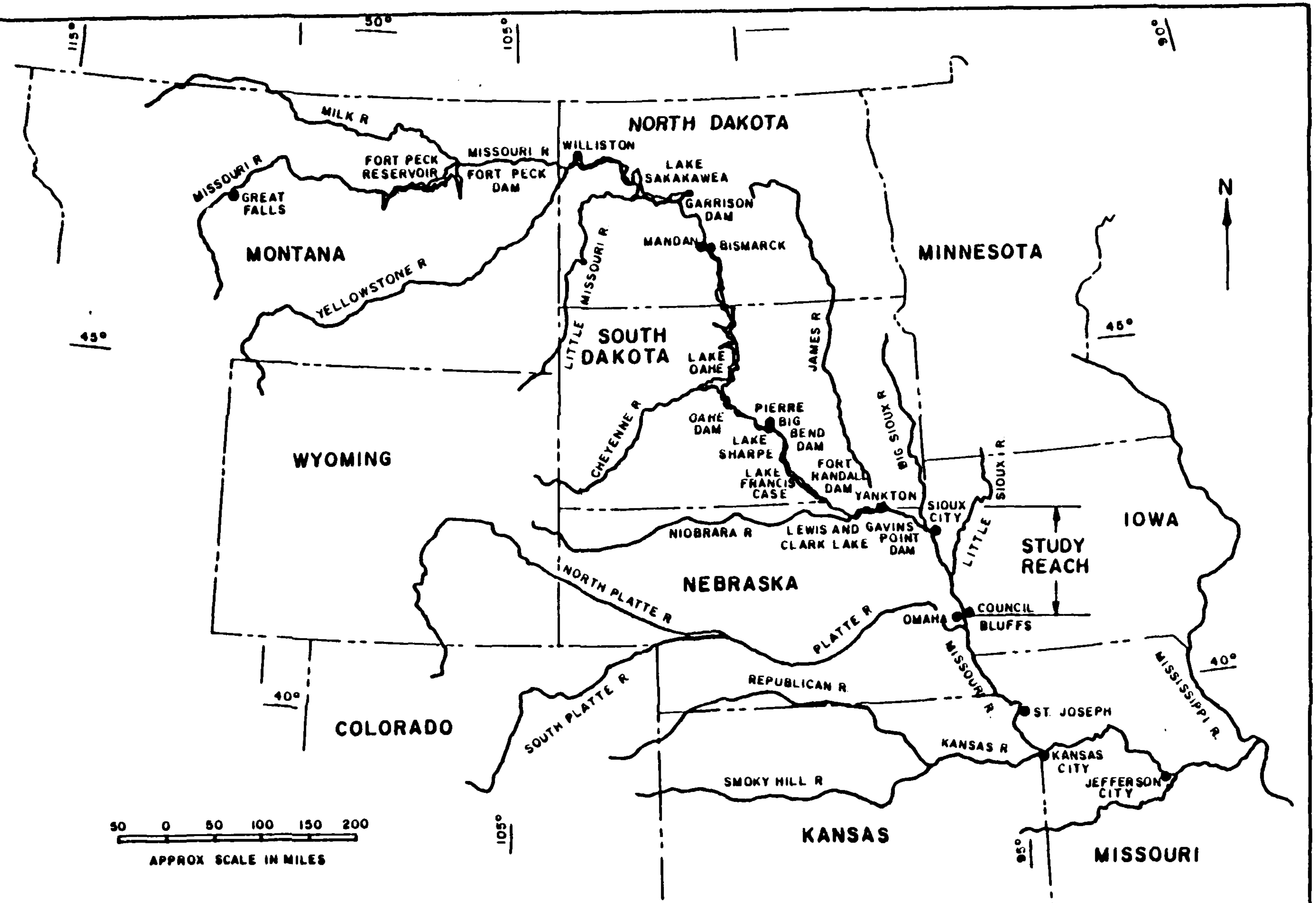


Figure 8. Missouri River basin

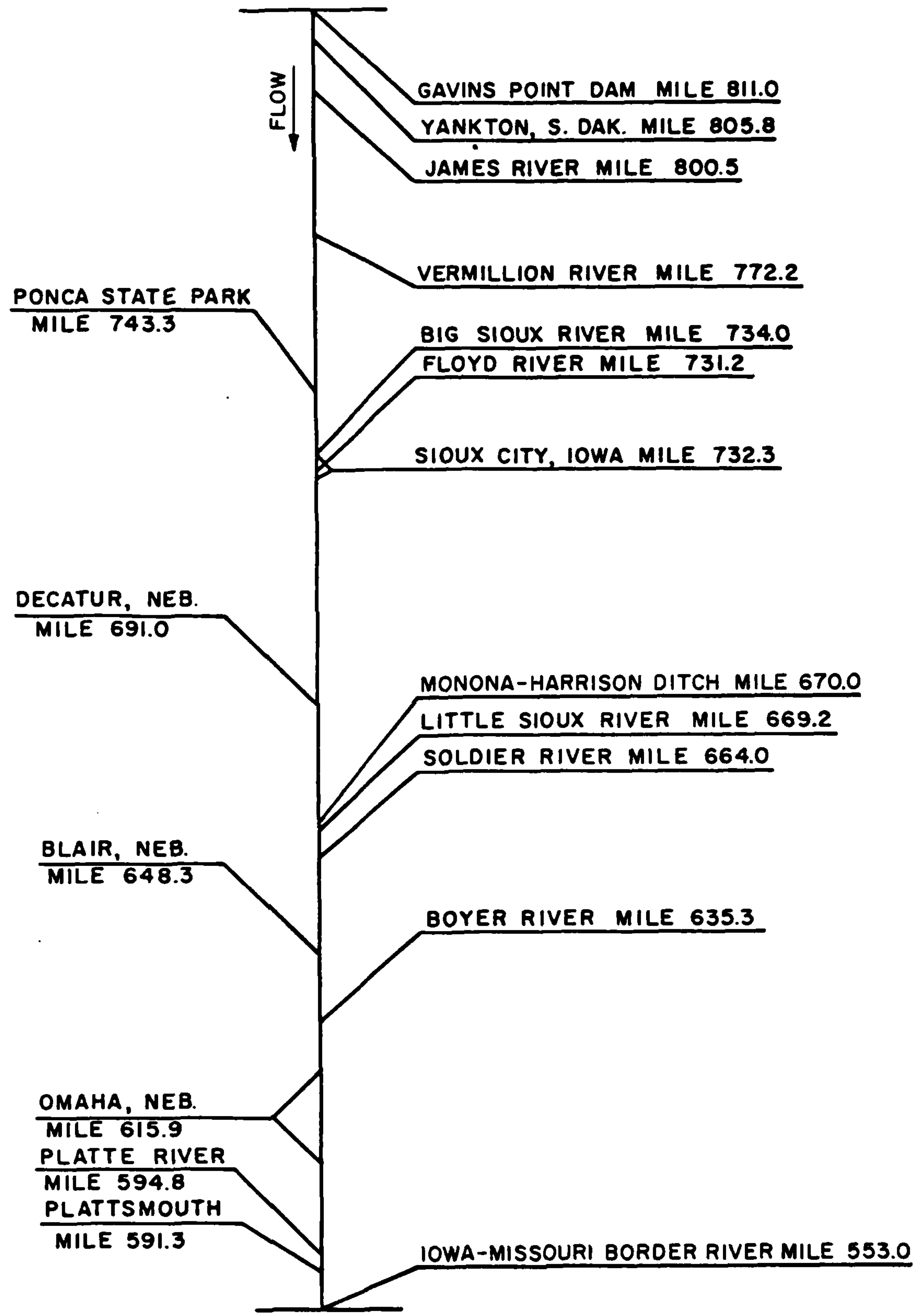


Figure 9. Schematic map of the study reach

Floyd, Monona-Harrison, Little Sioux, Soldier and Boyer) join the Missouri River between Gavins Point Dam and Omaha, as shown in figures 8 and 9. The discharge hydrograph for each tributary was assumed to consist of two constant components: a high discharge (Q_1) for the first four months (April to July) of the navigation season and a low flow (Q_2) for the remaining eight months of the year. The values of Q_1 and Q_2 were computed such that $Q_2 = Q_1/4$ while yielding an average annual flow volume equal to the observed value for the available period of record (U.S. Army Corps of Engineers, 1969). The annual discharge hydrograph thus computed and used in all simulation runs is summarized in table 2.

2. Geometric and Bed-Sediment Data. The study reach is represented by rectangular cross-sections, with widths varying between 1800 and 1020 feet from Gavins Point Dam to RM 762.2 (upstream of Ponca), varying between 750 and 625 feet from RM 752.4 to 703.7, and with a constant width of 00 feet below R.M. 703.7 down to Omaha. Bed elevations were estimated from observed water surface slopes (U.S. Army Corps of Engineers, 1981); the effect of cutoffs is included by increasing bed slopes in the affected subreaches (DeSoto Bend and California cutoffs). Bed-material distribution is assumed to be nearly the same in the whole reach with constant $D_{50} = 0.297$ mm, but slightly more coarse fractions in the subreaches near the dam. Geometric and bed-sediment characteristics for the whole reach, G.P. Dam to Omaha, are summarized in tables 3 and 4.

3. Sediment Inputs from Tributaries and Bank Erosion. Tributary sediment discharges are computed from power-law relations of the form

$$Q^t_{s,i} = a_i \, (Q^t_i)^{b_i} \tag{26}$$

Table 2

Summary of Discharge Hydrographs

Inflow Point	River Mile	Discharge (cfs) in each trimester April to July	August to November	December to March
Upstream (G.P.D.)	811.0	36,000	36,000	15,000
Tributaries				
James	800.5	776	192	192
Vermillion	772.2	240	60	60
Big Sioux	734.2	1,668	417	417
Floyd	731.2	348	87	87
Monona-Harrison	670.0	432	108	108
Little Sioux	669.2	1,560	390	390
Soldier	664.0	248	62	62
Boyer	635.2	590	147	147
Total for all tributaries		5,862	1,463	1,463
Total (upstream & tributaries)		41,862	37,463	16,463

Table 3

Summary of Geometric and Bed Sediment Data

Sec. No.	River Mile	Channel Width (ft)	Bed Elevation (ft. MSL)	Bed Slope (x 10^3)	D_{50} (mm)	Bed Material Size Dist.**
22 (G.P. Dam)	810.9	1800	1161.34	0.228	0.297	SD1
21	801.2	1540	1149.61	0.228	0.297	SD2
20	791.4	1800	1137.87	0.228	0.297	SD2
19	781.7	1540	1126.13	0.212	0.297	SD2
18	771.9	1280	1115.22	0.212	0.297	SD2
17	762.2	1020	1104.30	0.212	0.297	SD2
16	752.4	750	1093.39	0.212	0.297	SD2
15	742.7	725	1082.48	0.182	0.297	SD2
14 (Sioux City)	732.9	700	1073.11	0.182	0.297	SD3
13	723.2	675	1063.74	0.208	0.297	SD3
12	713.4	650	1053.03	0.208	0.297	SD3
11	703.7	625	1042.32	0.177	0.297	SD3
10	693.9	600	1033.22	0.177	0.297	SD3
9	684.2	600	1024.10	0.215*(0.185)	0.297	SD3
8	674.4	600	1013.03	0.185	0.297	SD3
7	664.7	600	1003.50	0.177	0.297	SD3
6	654.9	600	994.39	0.177	0.297	SD3
5	645.2	600	985.28	0.222*(0.145)	0.297	SD3
4	635.4	600	973.85	0.222*(0.145)	0.297	SD3
3	625.7	600	962.43	0.145	0.297	SD3
2 (Omaha)	615.9	600	954.96	0.145	0.297	SD3
1	606.2	600	947.50	--	--	--

*Increased slope in cutoffs, with pre-cutoff slopes indicated in parentheses.

**See table 4 for the distribution SD1, SD2, SD3

Table 4

Bed-Material Size Distributions

	Cumulative Distribution Function (CDF) (fraction finer than D)		
D(mm)	SD1	SD2	SD3
0.062	0.000	0.000	0.000
0.149	0.105	0.105	0.105
0.297	0.500	0.500	0.500
0.590	0.850	0.850	0.850
1.190	0.935	0.935	0.935
2.400	0.970	0.970	0.970
4.800	0.989	0.997	1.000
9.520	0.994	1.000	1.000
19.100	1.000	1.000	1.000
D_{50}(mm)	0.297	0.297	0.297

where a_i and b_i are coefficients obtained from the sediment rating curve for the tributary at node i; $Q^t_{s,i}$ = tributary sediment discharge (tons/day) at node i; and Q^t_i = tributary water discharge (cfs) at node i. The values of the coefficients a_i and b_i were obtained by plotting observed monthly total suspended discharge (including wash load) against average monthly water discharge (U.S. Army Corps of Engineers, 1972; Schultz and Matthew, 1977); the values of a_i were further adjusted to exclude sediment fractions less than sand size (0.062 mm). Table 5 lists the computed values of a_i and b_i for each tributary. Plots of sediment rating curves for each tributary (for which data were available) are given in IIHR Report No. 267.

Because of the large subreach length (9.75 miles) used in the present runs, all tributaries could not be represented separately. Due to the small distance separating them, the Big Sioux and Floyd were combined and represented as one tributary located at node no. 14. In the same way, the Monona-Harrison and Little Sioux were combined at node no. 8 (node numbers increase in the upstream direction). Average size distributions of sediment discharge for each tributary, derived from available data, are presented in table 6.

The reach between Gavins Point Dam and Ponca (about 58 miles) is assumed to have erodible banks. The observed rates of bank erosion vary between 2.12 and 5.58 acres/mile/year (U.S. Army Corps of Engineers, 1981). Assuming a bank height of ten feet containing 25% of sand size material or coarser (based on the report by Gorene, 1960), the volumetric rate of bank erosion varies from 657 to 1732 cft/mile/day. Table 7 presents the rates of bank erosion adopted for each subreach between Gavins Point Dam and Ponca. Size

Table 5

Summary of Sediment Rating Curves Data for Tributaries

Name of Tributary	River Mile (1960)	Sediment discharge coefficients a_i** All Fractions	Sand Size Only	b_i	Location (RM of computational section)
James	800.5	0.0299*	.002652*	1.5790*	801.1
Vermillion	772.2	0.0299*	.002652*	1.5790*	781.6
Big Sioux	734.2	0.0299	.002652	1.5790	---
Floyd	731.2	.01327	.001177	1.9776	---
Big Sioux & Floyd	---	.01534	.001360	1.6400	732.9
Monona-Harrison	670.0	.0371	.003345	2.1893	---
Little Sioux	669.2	.004707	.003431	2.0328	---
Monona-Harrison & Little Sioux	---	.00363	.0002634	2.1220	674.4
Soldier	664.0	.002690	.0001963	2.8553	664.6
Boyer	635.2	.001427	.00002854	2.6633	635.4

*Assumed values

**Corresponds to sediment discharge in tons/day and water discharge in ft^3/sec (cfs)

Table 6

Size Distributions of Tributary Sediment Discharge

		Sediment Discharge (in Percent) for each Size Fraction					
Name of Tributary	% of Total Sediment Discharge >.062 mm	.062 mm-.149 mm	.149-.297	.297-.590	.590-1.19	1.19-2.40	2.40-4.80
James*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Vermillion*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Big Sioux*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Floyd	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Monona-Harrison*	8.87	39.0	43.3	12.7	5.0	0.0	0.0
Little Sioux	7.30	65.0	28.4	6.6	0.0	0.0	0.0
Soldier*	7.30	65.0	28.4	6.6	0.0	0.0	0.0
Boyer	2.00	100.0	0.0	0.0	0.0	0.0	0.0

*Assumed values

Table 7

Rates of Bank Erosion

Physical Quantity	Miles Below G.P. Dam		
	0-20	21-40	41-60
Erosion rate (acres/mile/year)	2.12	3.77	5.58
Volumetric erosion rate assuming 10 ft. bank height (cft/mile/day)	2630	4680	6930
Volumetric erosion rate assuming 25% in sand size (cft/mile/day)	657	1170	1732
Location (RM of computational section)	810.9-791.4	791.4 771.9	771.9 752.4

distributions of eroded bank materials are assumed to be the same as that of the initial bed material in each subreach.

C. Presentation of Results

This section presents results of ten simulation runs performed using the new version of IALLUVIAL. These simulation runs are used to present a comparison of results of the previous version of IALLUVIAL with those of the present version, to present results for different armoring procedures included in the present version, and to investigate the sensitivity of the pattern of bed and water-surface evolutions in the study reach to cutoff effects, variations in bed-material size distribution, and the quantity of coarser sediments responsible for bed armoring. For ready reference, these simulation runs are designated as Run R1, Run R2, etc., and briefly described in table 8.

For all simulation runs listed in table 8, the subreach length, Δx = 9.75 miles, and the time interval, ΔT = 30 days, are kept constant. The downstream boundary is located 9.75 miles downstream from Omaha for all runs except R9 and R10. The downstream water surface elevations, calculated as uniform flow depths for the given water discharge and initial local bed slope, are fixed. The computed values of bed-elevation changes (Δz), median bed-material size (D_{50}), and the armor-coverage factor (ACF) after 20 years of simulation (1956-76) for the runs R1 through R8 are presented in tables 9 through 11. The results of runs R9 and R10 are presented and discussed in Section IV.D.9 and IV.D.10.

The computed changes in bed and water-surface elevations (for Q = 36,000 cfs), changes in D_{50} and armor-coverage factor (ACF) after 3, 8, 16 and 20 years of simulation for runs R1 and R2 are plotted in figures 10 through 25.

Table 8

Description of Simulation Runs

Run Name	Brief Description
R1	Old armoring and sorting procedure (near dam) in the previous version of IALLUVIAL. Water discharge hydrograph, geometric and bed-sediment characteristics are given by tables 2 through 7; $C_1 = C_2 = C_3 = 1.0$ in Eqs. (21), (22), and (23), CA(t,k) = constant = 0.50 and l(t) constant = 7 (indicates last two fractions are always immobile) in Eq. (16); includes cutoffs.
R2	New version of IALLUVIAL with same input data as R1 (tables 2 through 7); $C_A(t,k)$ and l(t) calculated internally by the new armoring procedure; $C_1 = C_2 = C_3 = 1.0$ in Eqs. (21), (22), and (23); includes cutoffs.
R3	Same as Run R2, with $C_1 = C_2 = C_3 = 0.80$ in Eqs. (21), (22), (23).
R4	Same as Run R2, without cutoffs.
R5	Same as Run R2, with extra 3% armoring fractions (4 feet below bed) in subreaches near Sioux City.
R6	Same as Run R2, with coarser bed material (D_{50} = 0.385 mm) in subreaches RM 684.15 to 742.65.
R7	Same as Run R2, with armoring procedure replaced by bed-layer procedure.
R8	Same as Run R2, with armoring procedure supplemented by surface-layer procedure.
R9	Same as Run R2, with the downstream boundary moved 48.75 miles further downstream.
R10	3-year run, with the same input as R2, to simulate the effects of DeSoto and California cutoffs.

Table 9

Summary of Computed Bed-Elevation Change (feet) After 20 Years

Node No.	River Mile	R1	R2	R3	R4	R5	R6	R7	R8	Obser. Changes in W.S. Elev. (ft)	Comp. Changes in W.S. Elev. for Run R2 (ft)
		Computed Bed-Elevation Changes* (feet) for Indicated Run									
22	810.9 (GPD)	3.63	5.45	6.07	5.22	5.54	5.52	4.05	2.25	5.20	6.56
21	801.1	3.25	4.89	5.30	5.84	4.88	4.89	2.29	2.33	4.20	4.11
20	791.4	1.24	2.25	2.33	2.73	2.23	2.12	-0.43	1.00	2.20	1.71
19	781.6	1.27	1.87	1.76	2.37	1.85	1.68	0.12	2.18	3.50	1.89
18	771.9	2.17	2.73	2.68	3.20	2.59	2.50	0.59	4.28	4.00	2.98
17	762.1	3.35	4.73	4.48	5.07	4.46	4.04	3.07	5.89	4.80	5.00
16	752.4 (Ponca)	5.36	6.81	6.66	7.09	6.29	5.07	6.23	7.49	5.90	5.77
15	742.6	5.06	6.00	5.36	5.68	5.29	3.37	4.05	6.11	5.90	5.55
14	732.9 (S. City)	6.56	6.79	5.85	6.27	6.05	4.15	4.43	6.52	6.00	6.21
13	723.1	7.92	7.18	6.87	6.78	7.14	5.44	6.37	7.31	7.70	5.85
12	713.4	6.97	6.11	6.34	6.06	6.76	5.55	4.03	6.75	6.00	4.82
11	703.6	5.80	5.14	5.40	5.22	6.07	5.00	5.74	5.81	4.90	5.13
10	693.9 (Decatur)	6.16	6.26	5.83	5.14	7.50	7.15	6.34	6.37	5.20	5.68
9	684.1	6.40	6.58	6.24	6.51	7.65	8.76	7.12	7.78	3.30	5.38
8	674.4	4.81	4.55	4.67	5.14	5.58	6.06	5.81	5.66	3.20	4.58
7	664.6	4.52	3.83	4.46	1.97	4.13	4.14	1.98	3.58	4.40	3.66
6	654.9	4.52	4.01	4.53	0.70	3.98	3.93	2.65	2.95	3.70	3.70
5	645.1	5.79	5.60	5.81	-0.05	5.72	5.97	2.03	4.81	2.00	2.68
4	635.4	3.89	3.65	3.89	1.61	2.53	3.26	0.46	3.80	-2.00	-0.12
3	625.6	-0.45	-0.50	-0.46	2.29	-1.25	-1.37	-0.52	-0.43	-1.90	-0.88
2	615.9 (Omaha)	-0.35	-0.32	-0.36	1.85	0.10	-0.36	0.83	-0.36	-1.00	-0.17
1	606.1	0.44	0.48	0.44	1.46	0.86	0.55	1.42	0.44	0.0	0.0

*Positive value indicates degradation; negative value indicates aggradation

Table 10

Summary of Computed Values of D_{50} (mm) After 20 Years

Node No.	River Mile	Computed D_{50}(mm) for Indicated Run R1	R2	R3	R4	R5	R6	R7	R8 *	Observed D_{50} (mm)
22	810.9 (GPD)	2.70	0.46	0.46	0.46	0.46	0.47	2.90	1.53	2.50
21	801.1	1.63	0.47	0.47	0.46	0.46	0.45	2.06	1.04	0.45
20	791.4	0.46	0.43	0.44	0.42	0.42	0.40	0.78	0.52	0.40
19	781.6	0.39	0.38	0.37	0.37	0.38	0.37	0.48	0.43	0.34
18	771.9	0.42	0.39	0.38	0.40	0.38	0.37	0.53	0.39	0.33
17	762.1	0.40	0.40	0.40	0.39	0.39	0.38	0.40	0.40	0.32
16	752.4 (Ponca)	0.38	0.38	0.36	0.37	0.38	0.35	0.93	0.36	0.33
15	742.6	0.35	0.36	0.33	0.35	0.36	0.37	0.91	0.35	0.33
14	732.9 (S. City)	0.35	0.39	0.36	0.36	0.40	0.42	0.32	0.37	0.34
13	723.1	0.38	0.38	0.39	0.39	0.39	0.42	0.57	0.38	0.37
12	713.4	0.38	0.37	0.37	0.36	0.39	0.43	0.55	0.37	0.33
11	703.6	0.37	0.36	0.36	0.38	0.38	0.45	0.65	0.38	0.35
10	693.9 (Decatur)	0.36	0.38	0.37	0.40	0.38	0.44	0.70	0.39	0.35
9	684.1	0.40	0.39	0.37	0.40	0.39	0.44	0.38	0.41	0.41
8	674.4	0.32	0.25	0.28	0.40	0.39	0.28	0.38	0.36	0.38
7	664.6	0.31	0.25	0.30	0.30	0.31	0.19	0.38	0.28	0.35
6	654.9	0.40	0.38	0.39	0.25	0.27	0.29	0.70	0.31	0.42
5	645.1	0.40	0.42	0.40	0.35	0.37	0.39	0.65	0.38	0.31
4	635.4	0.42	0.42	0.42	0.34	0.27	0.41	0.31	0.42	0.31
3	625.6	0.36	0.36	0.36	0.32	0.22	0.34	0.89	0.36	0.30
2	615.9 (Omaha)	0.31	0.31	0.31	0.35	0.33	0.32	1.04	0.31	0.26
1	606.1	0.33	0.32	0.33	0.35	0.34	0.35	0.64	0.33	0.26

*Area-weighted surface-layer D_{50} given by Eq. (25)

Table 11

Summary of Computed Values of Armor-Coverage Factor (Fraction) after 20 Years

Node No.	River Mile	Computed ACF for Indicated Run R1	R2	R3	R4	R5	R6	R7	R8
22	810.9 (GPD)	0.39	1.00	1.00	0.97	1.00	1.00	0.0	0.11
21	801.1	0.25	0.64	0.64	0.70	0.63	0.64	0.0	0.06
20	791.4	0.07	0.16	0.16	0.22	0.15	0.15	0.0	0.02
19	781.6	0.07	0.09	0.08	0.13	0.09	0.08	0.0	0.01
18	771.9	0.10	0.10	0.10	0.14	0.10	0.09	0.0	0.0
17	762.1	0.15	0.03	0.03	0.02	0.03	0.03	0.0	0.0
16	752.4 (Ponca)	0.22	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	742.6	0.21	0.0	0.0	0.0	0.02	0.0	0.0	0.0
14	732.9 (S. City)	0.09	0.0	0.0	0.0	0.05	0.0	0.0	0.0
13	723.1	0.0	0.0	0.0	0.0	0.06	0.0	0.0	0.0
12	713.4	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0
11	703.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	693.9 (Decatur)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	684.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	674.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	664.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	654.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	645.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	635.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	625.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	615.9 (Omaha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	606.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

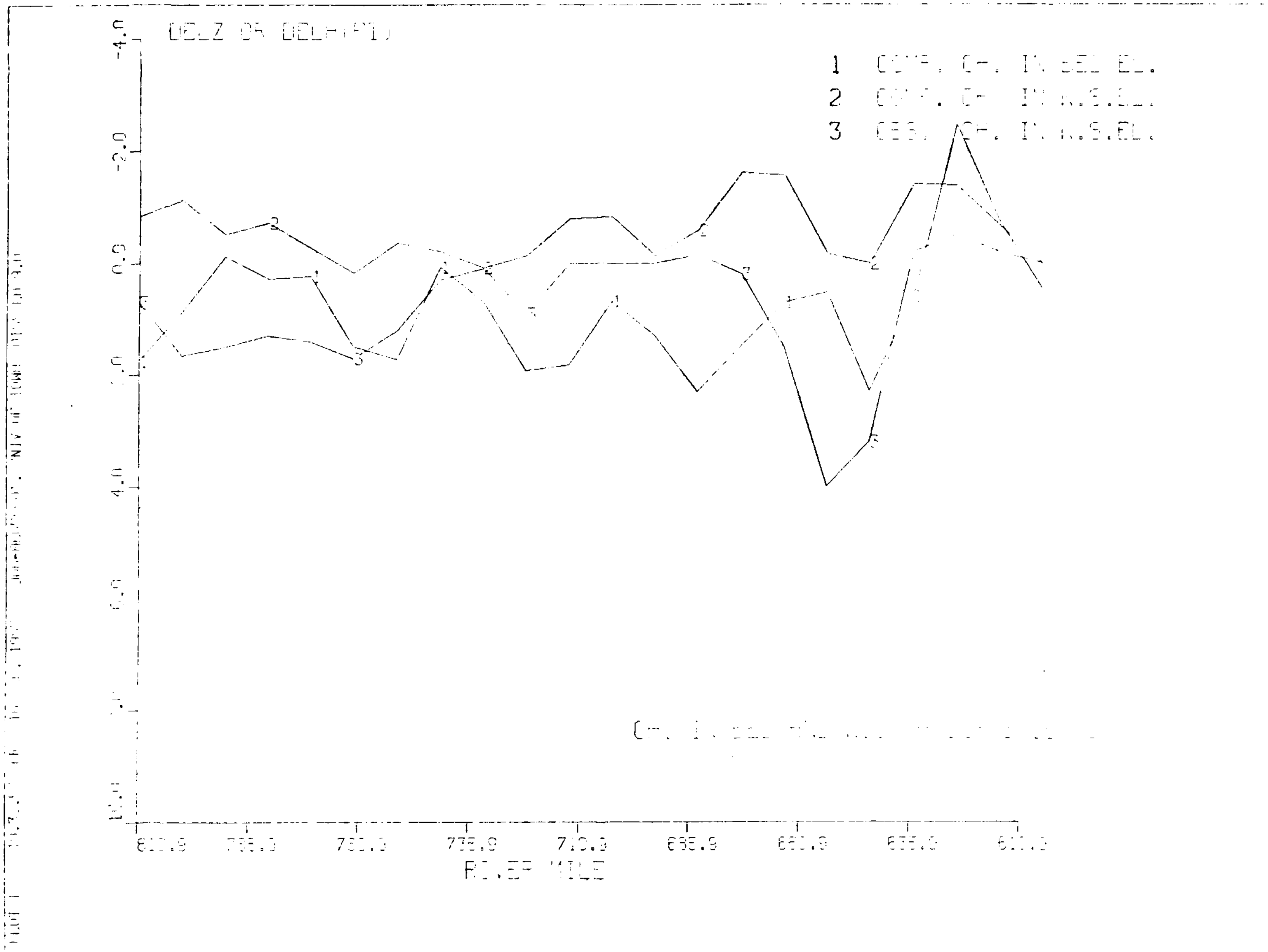


Figure 10. Change in bed and water-surface elevations for Run R1 after 3 years

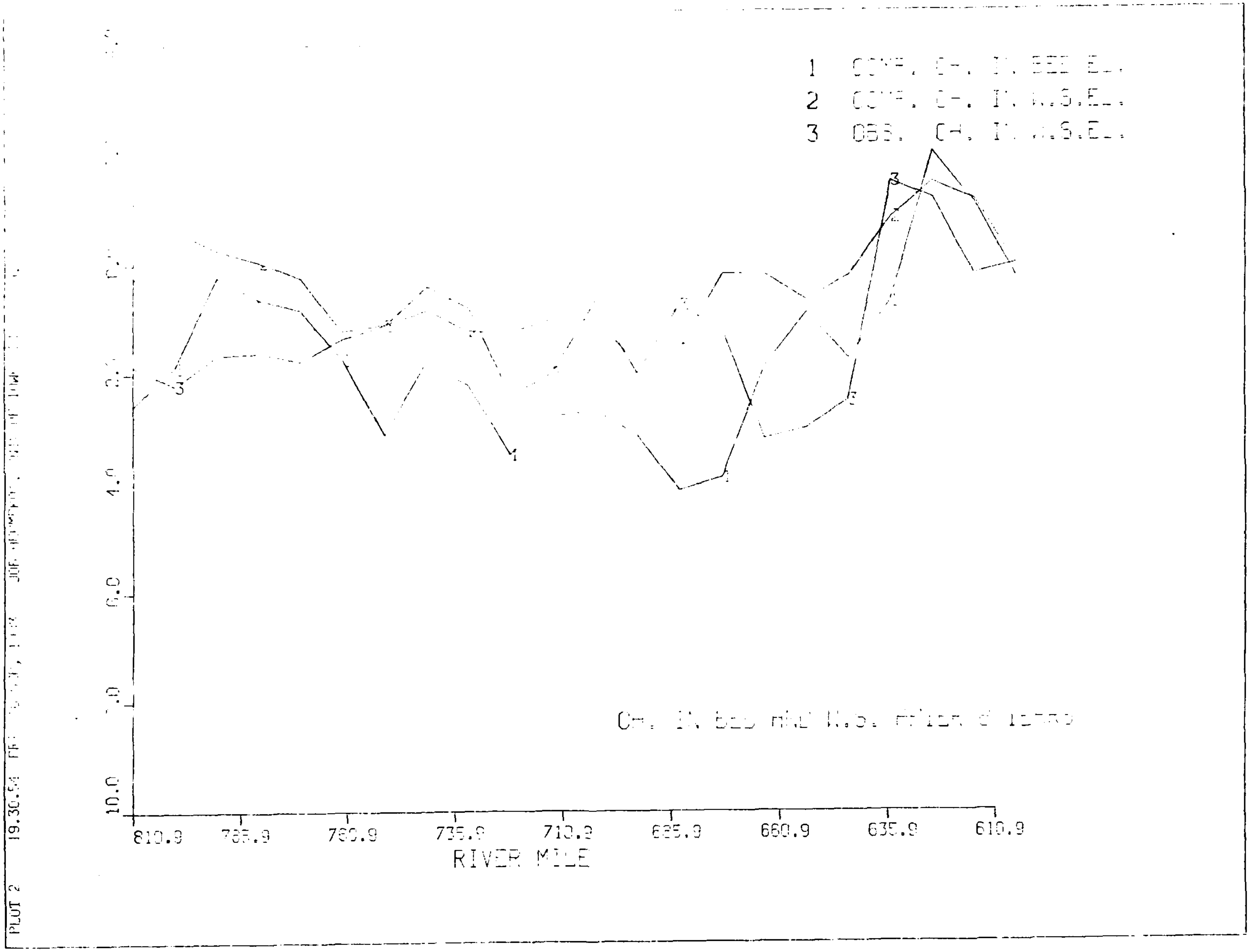


Figure 11. Change in bed and water-surface elevations for Run R1 after 8 years

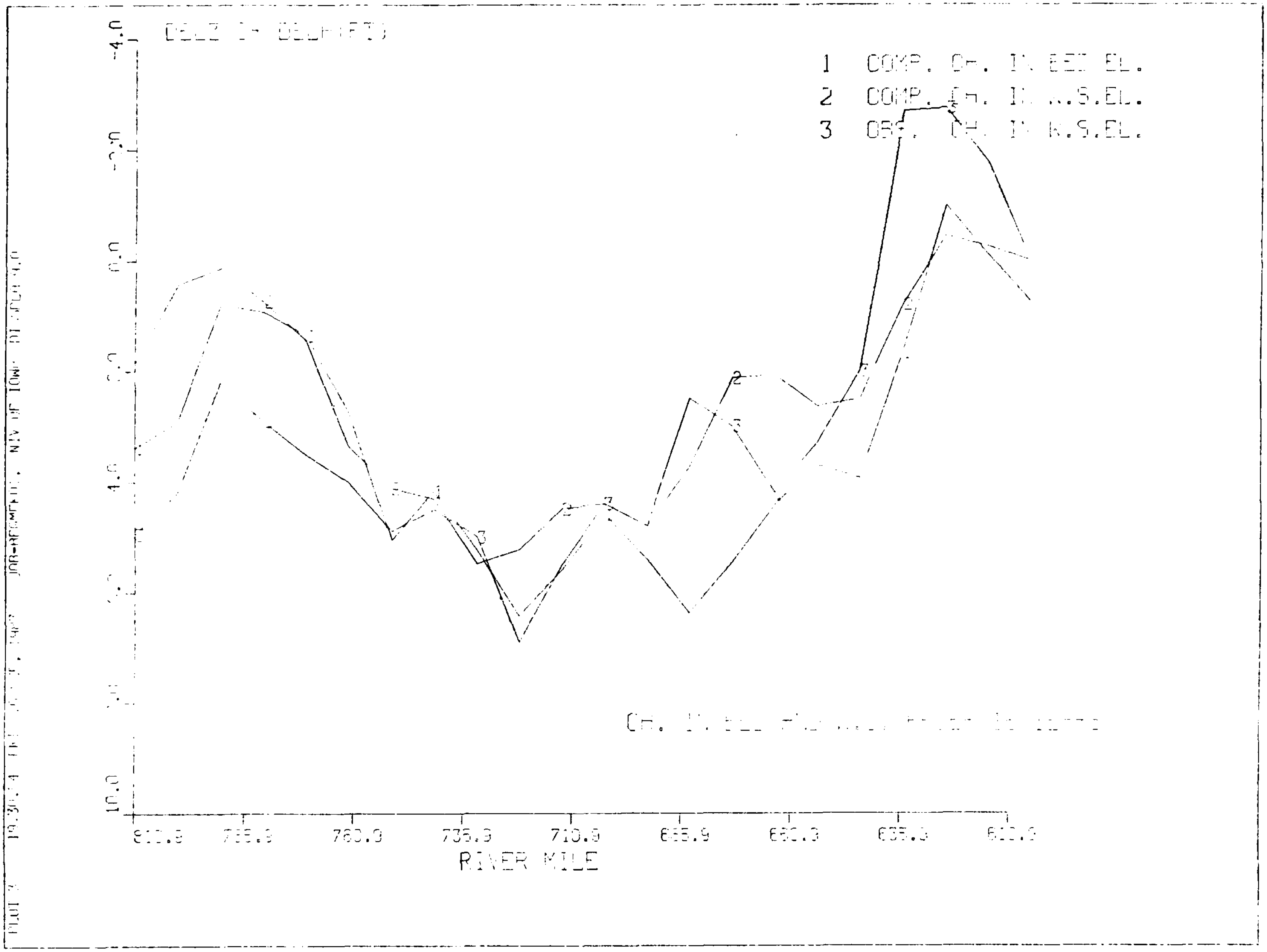


Figure 12. Change in bed and water-surface elevations for Run R1 after 16 years

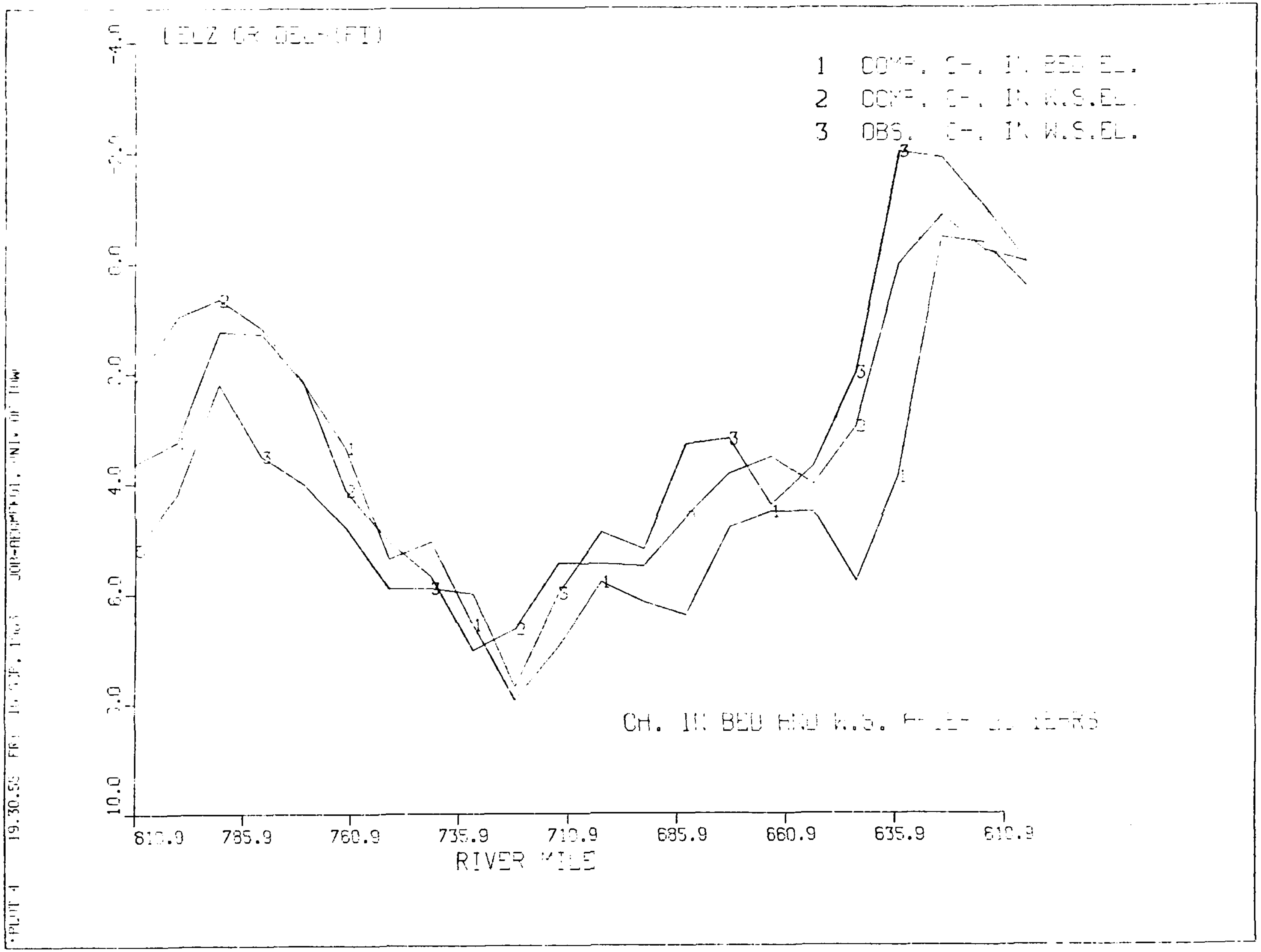


Figure 13. Change in bed and water-surface elevations for Run R1 after 20 years

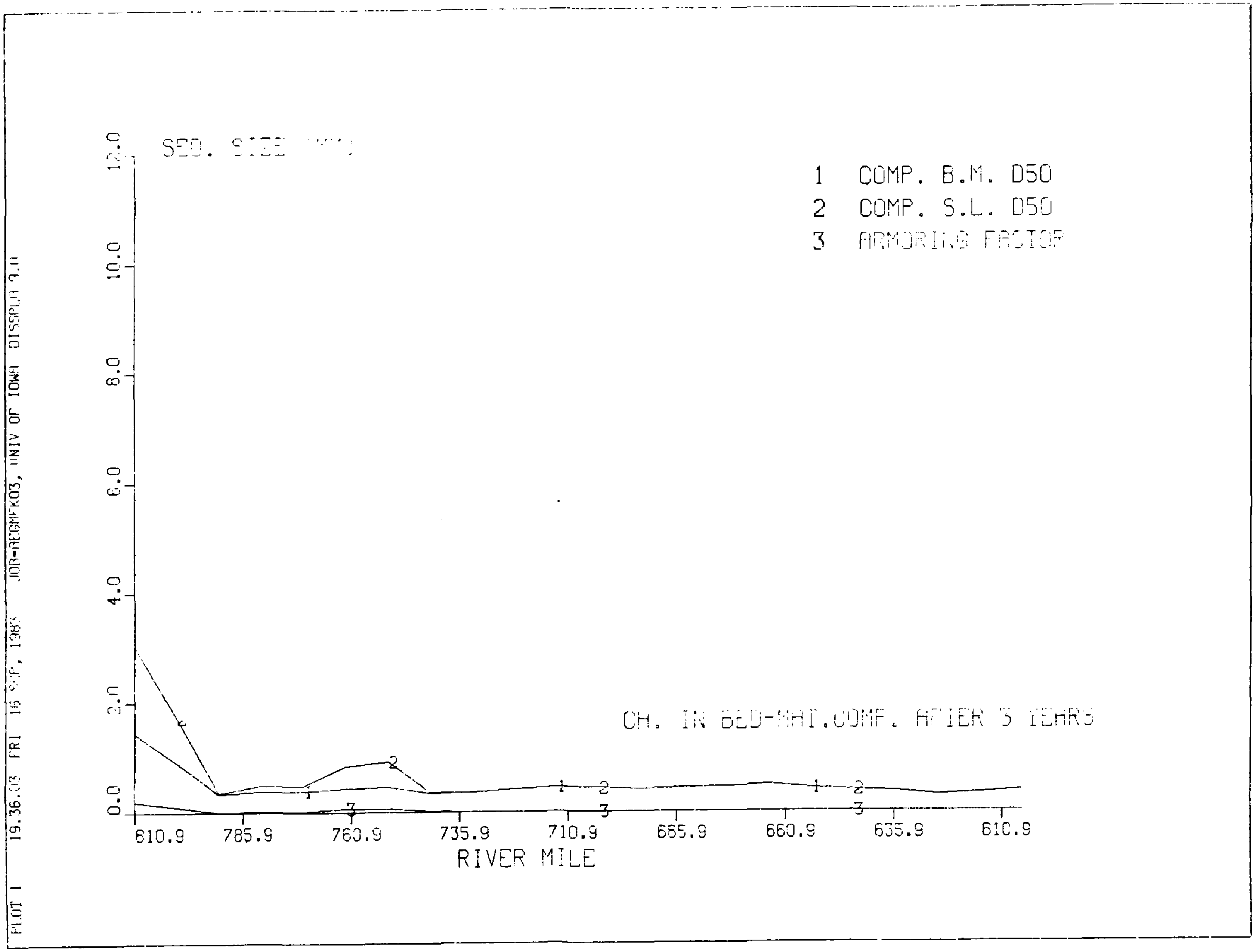


Figure 14. Change in bed-material composition for Run R1 after 3 years

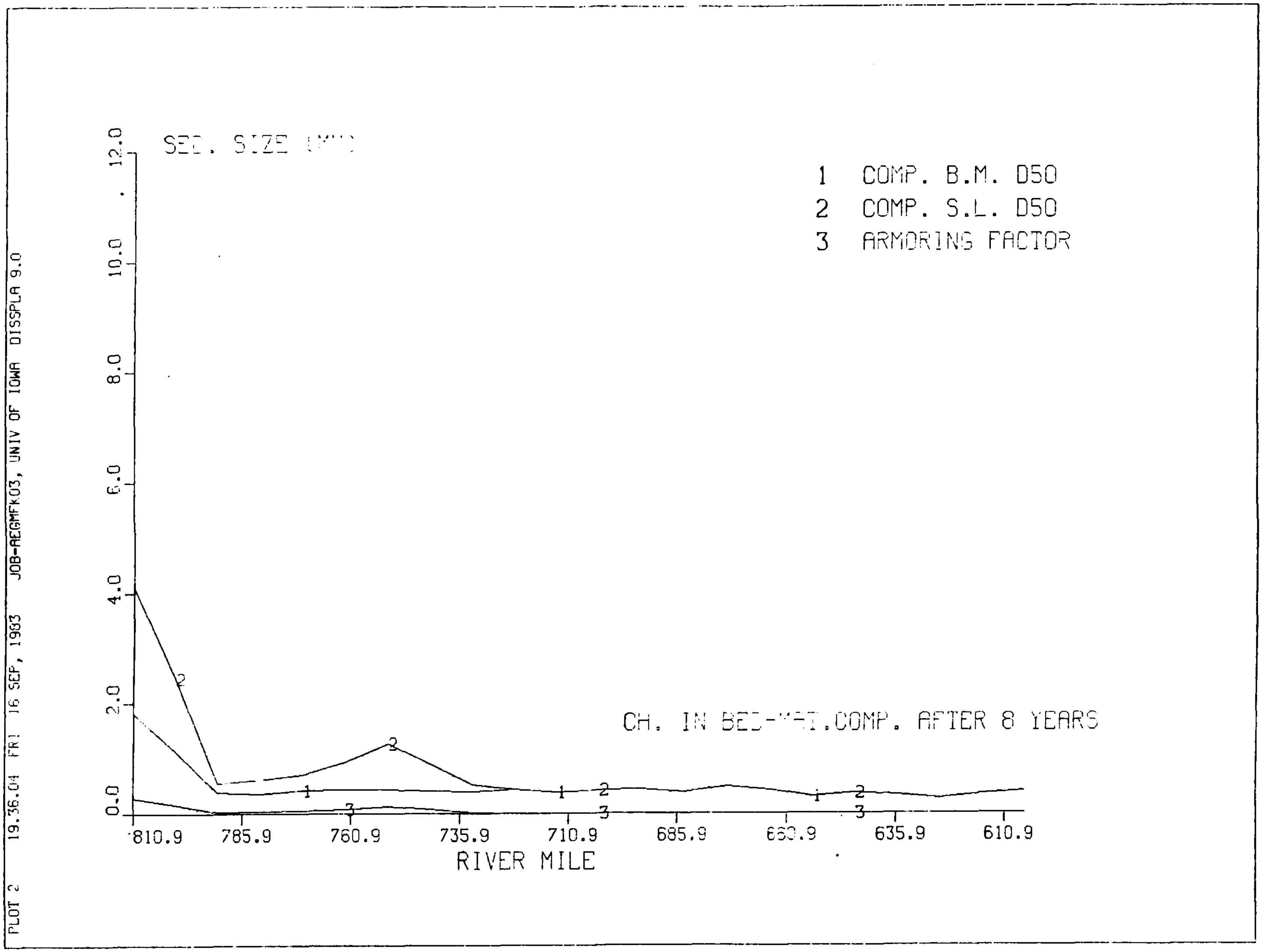


Figure 15. Change in bed-material composition for Run R1 after 8 years

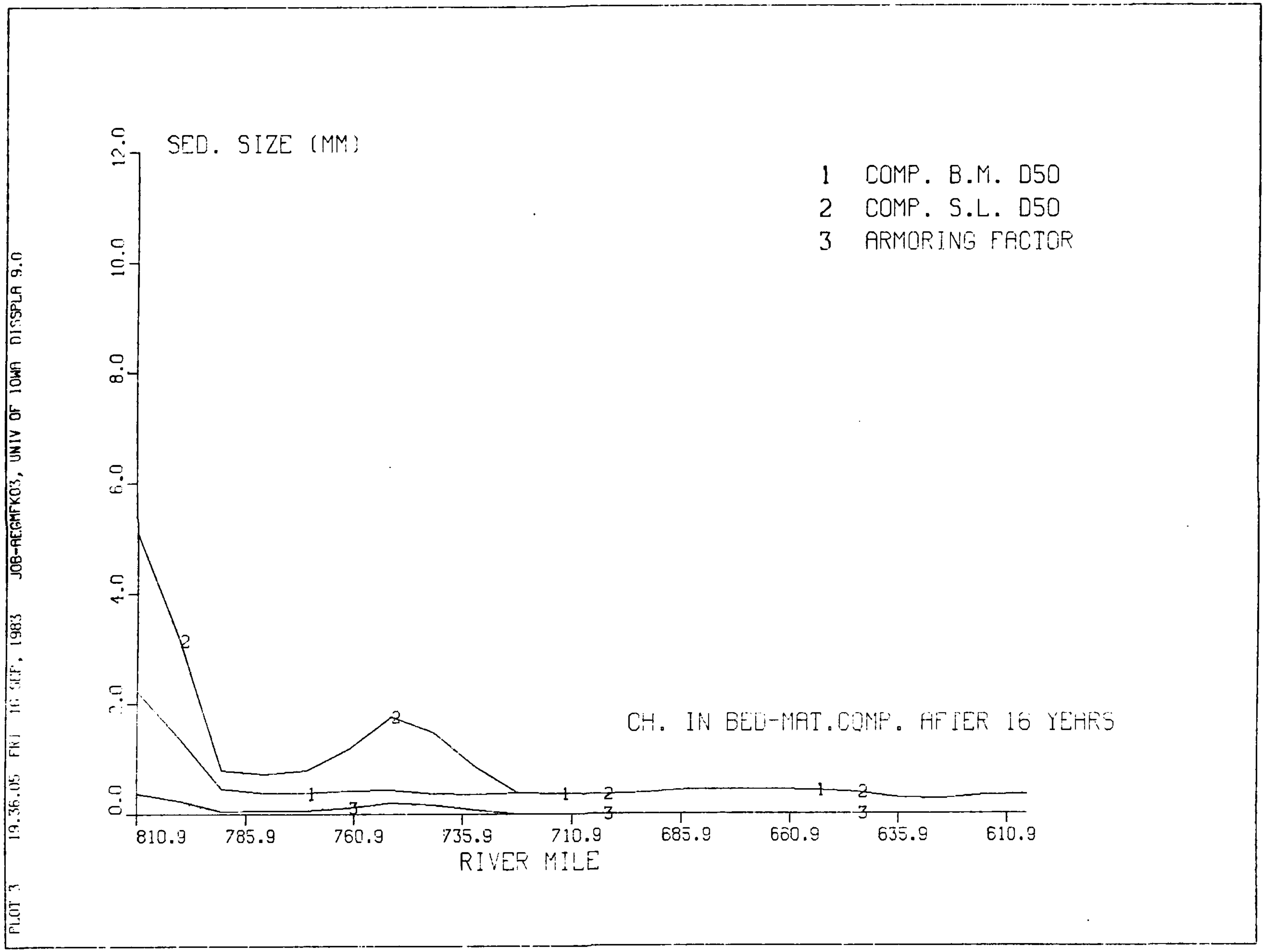


Figure 16. Change in bed-material composition for Run R1 after 16 years

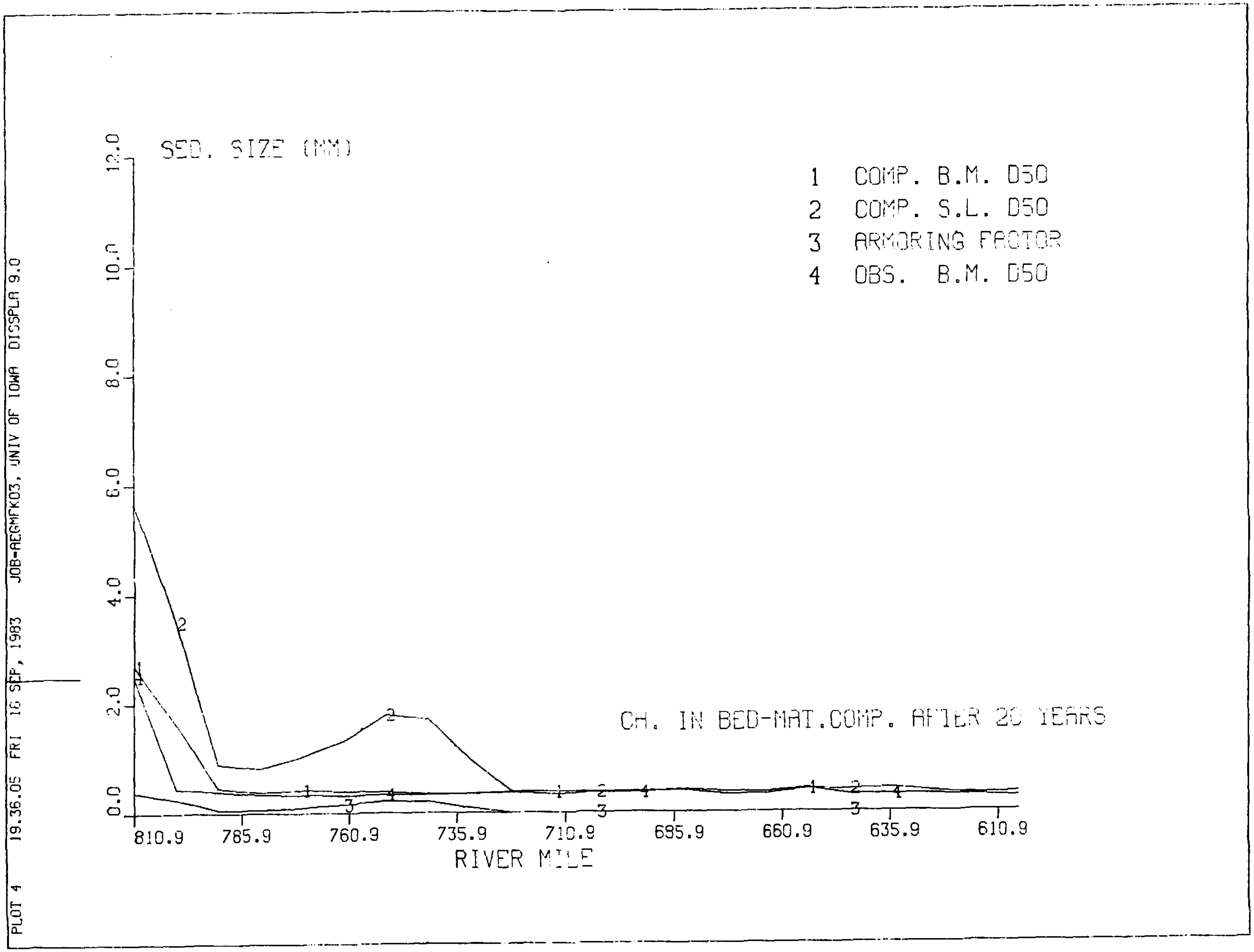


Figure 17. Change in bed-material composition for Run R1 after 20 years

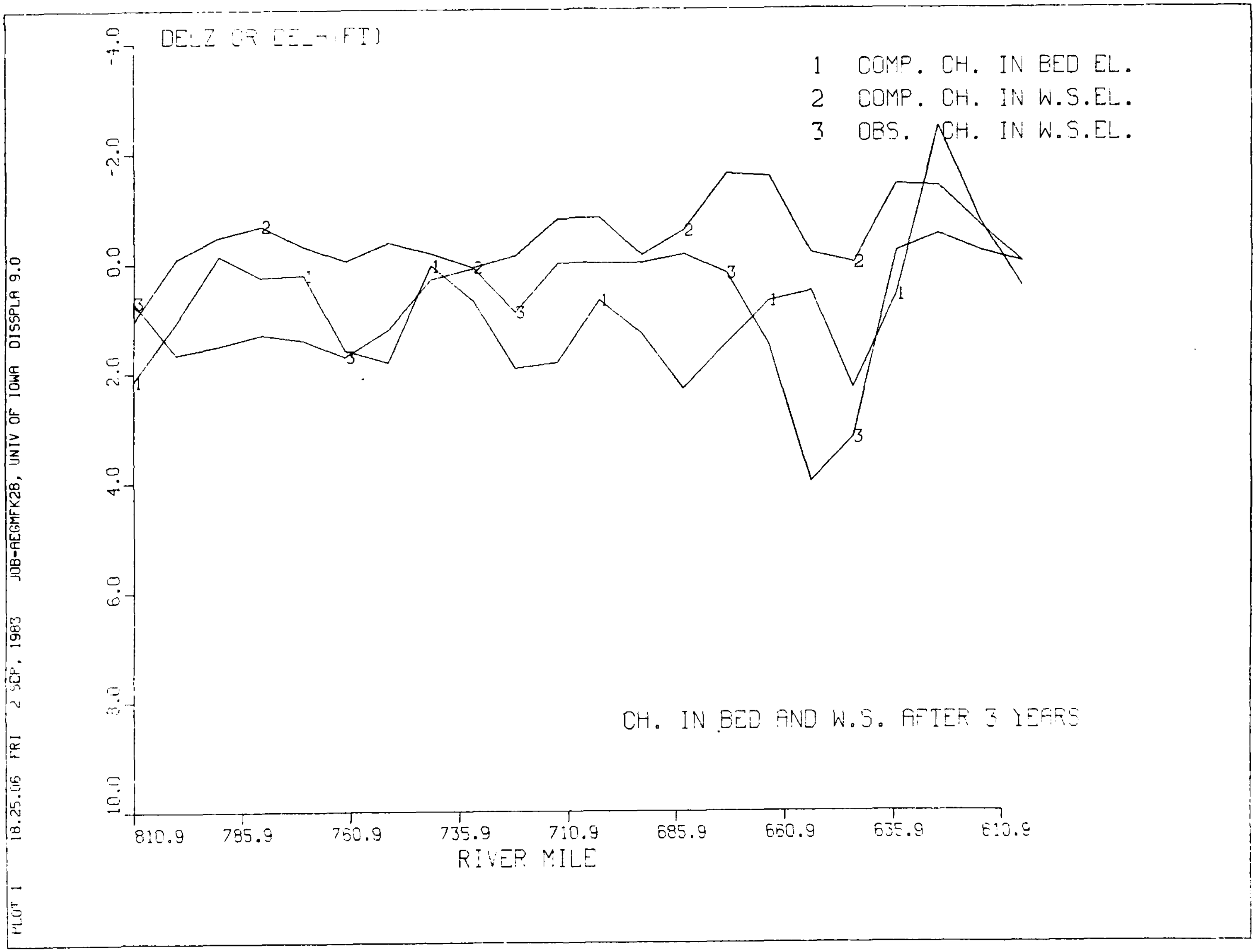


Figure 18. Change in bed and water-surface elevations for Run R2 after 3 years

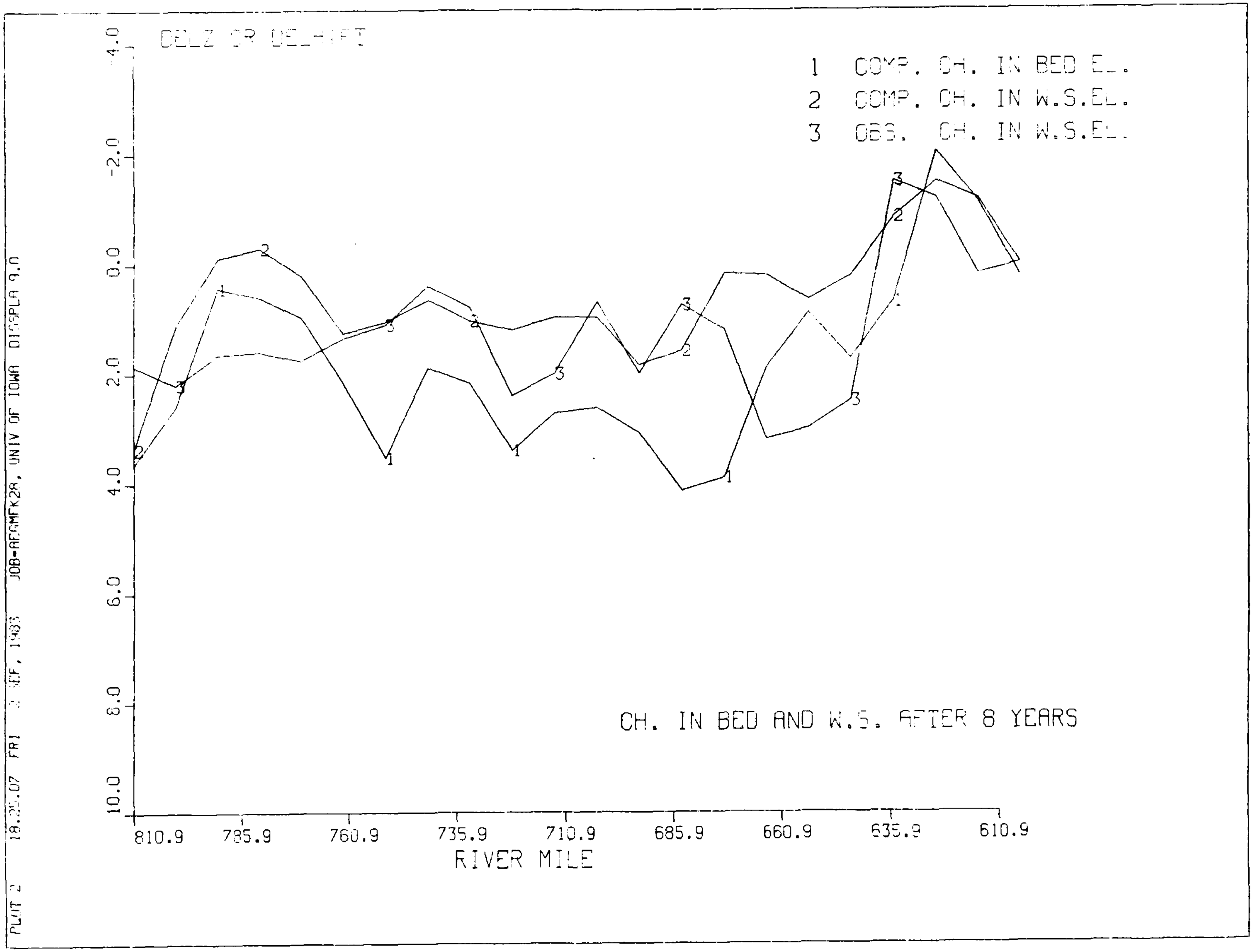


Figure 19. Change in bed and water-surface elevations for Run R2 after 8 years

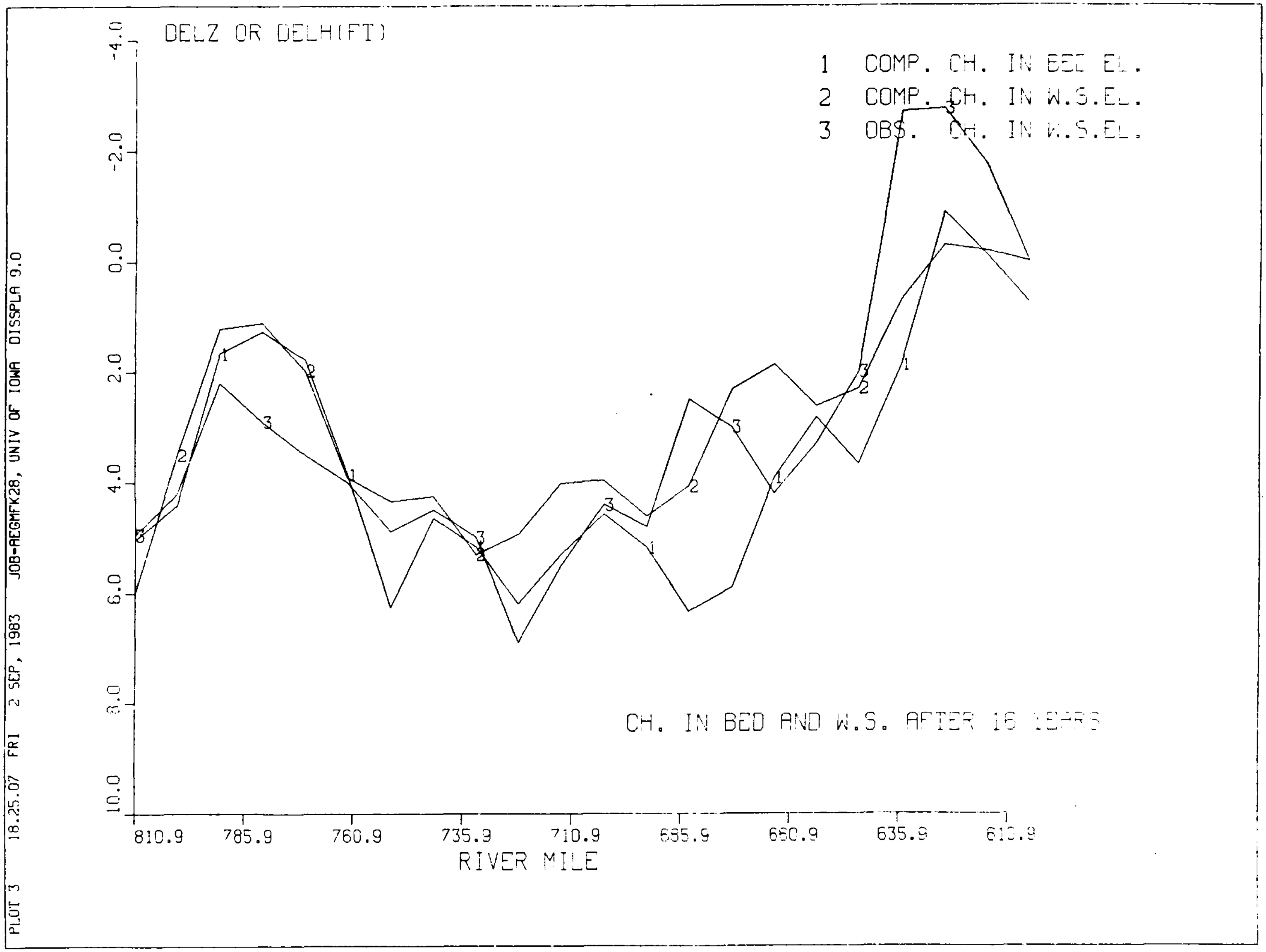


Figure 20. Change in bed and water-surface elevations for Run R2 after 16 years

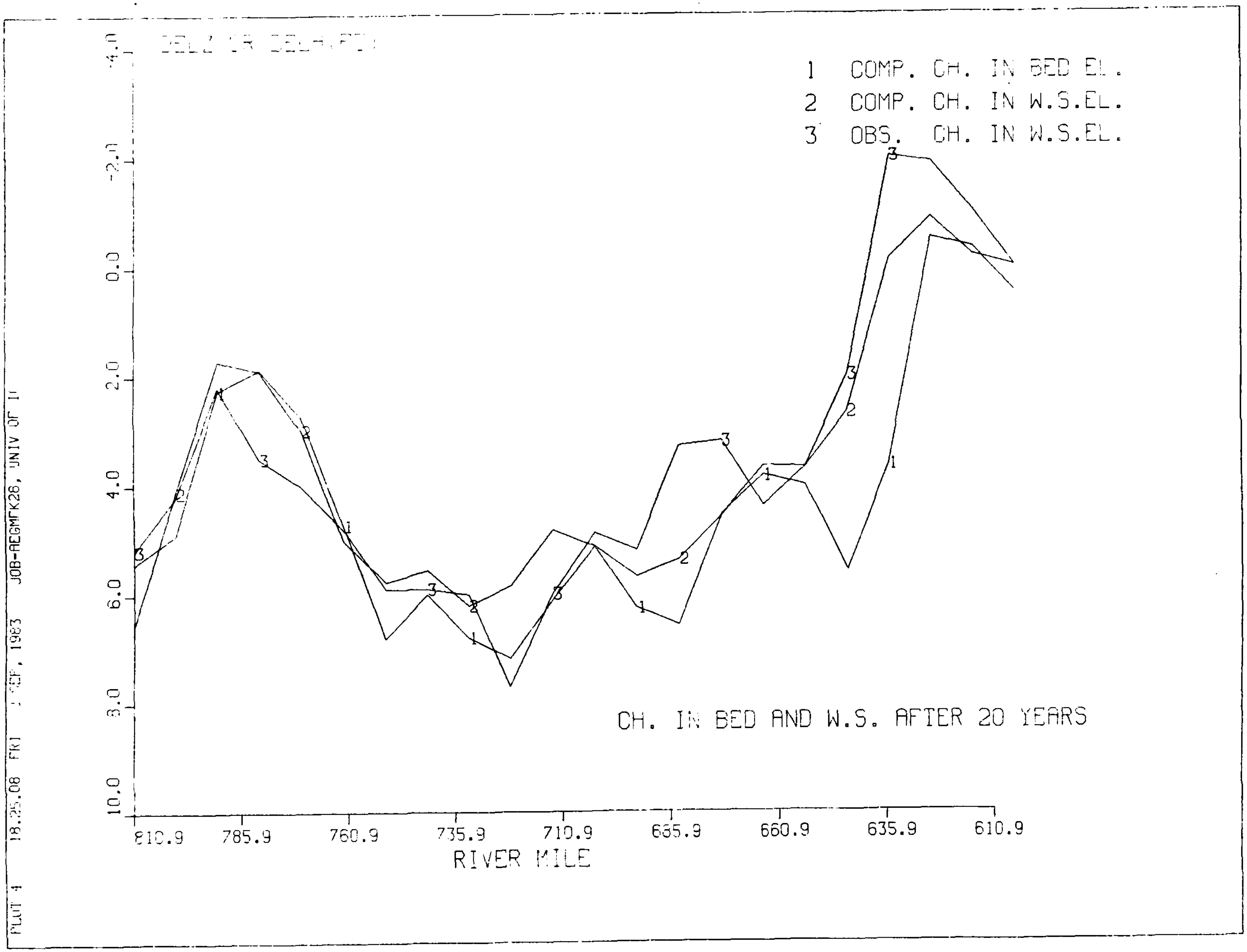


Figure 21. Change in bed and water-surface elevations for Run R2 after 20 years

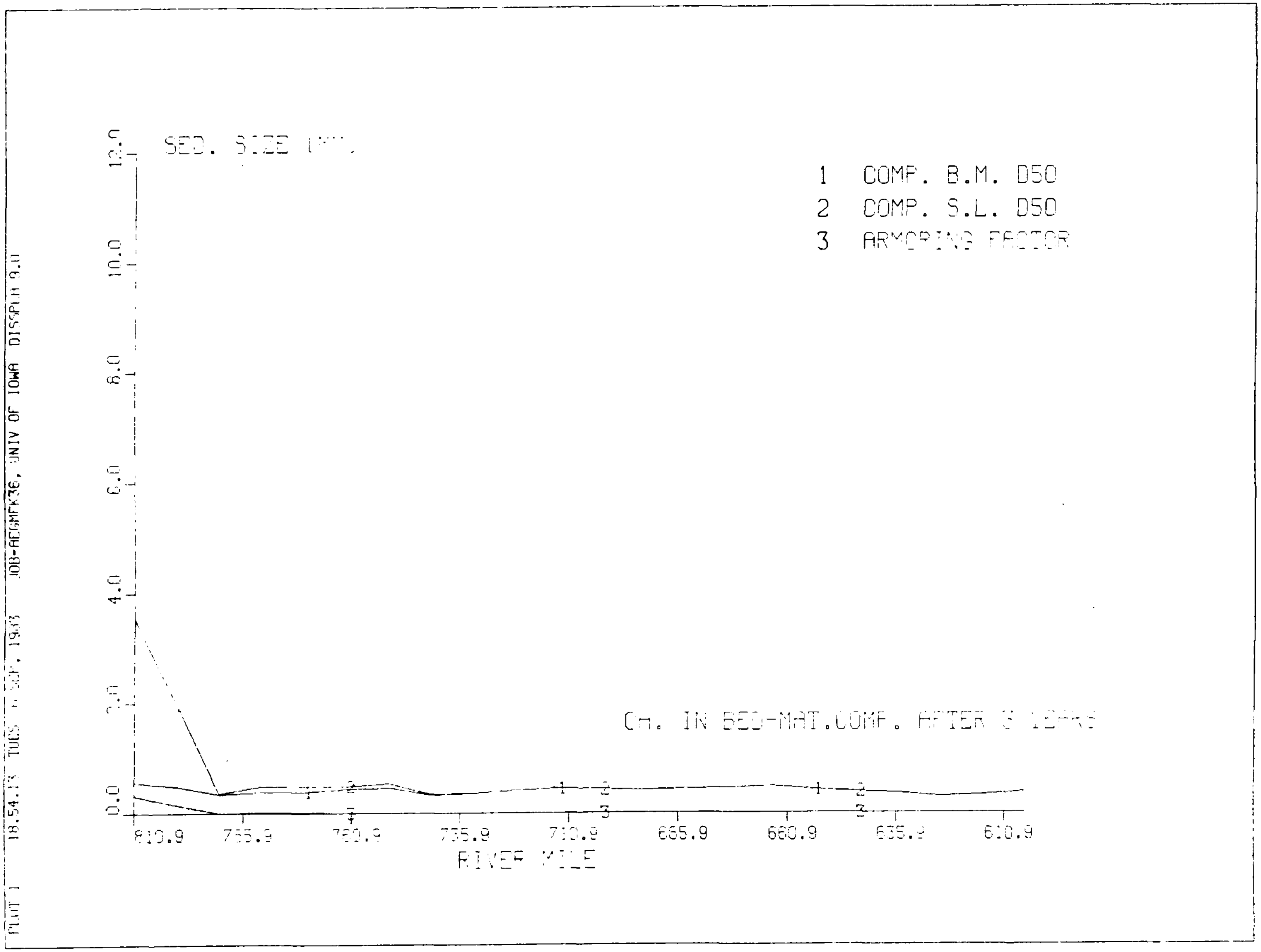


Figure 22. Change in bed-material composition for Run R2 after 3 years

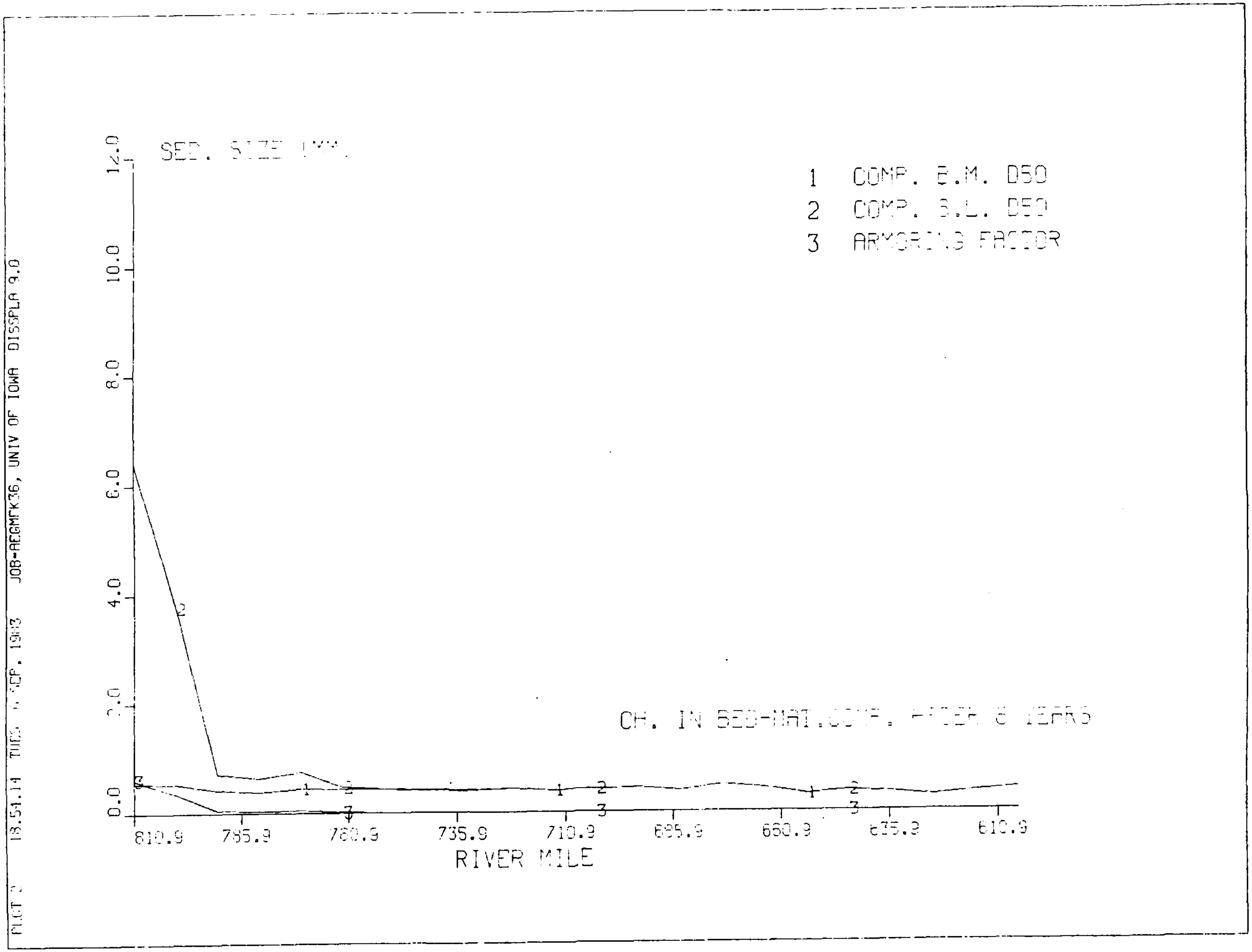


Figure 23. Change in bed-material composition for Run R2 after 8 years

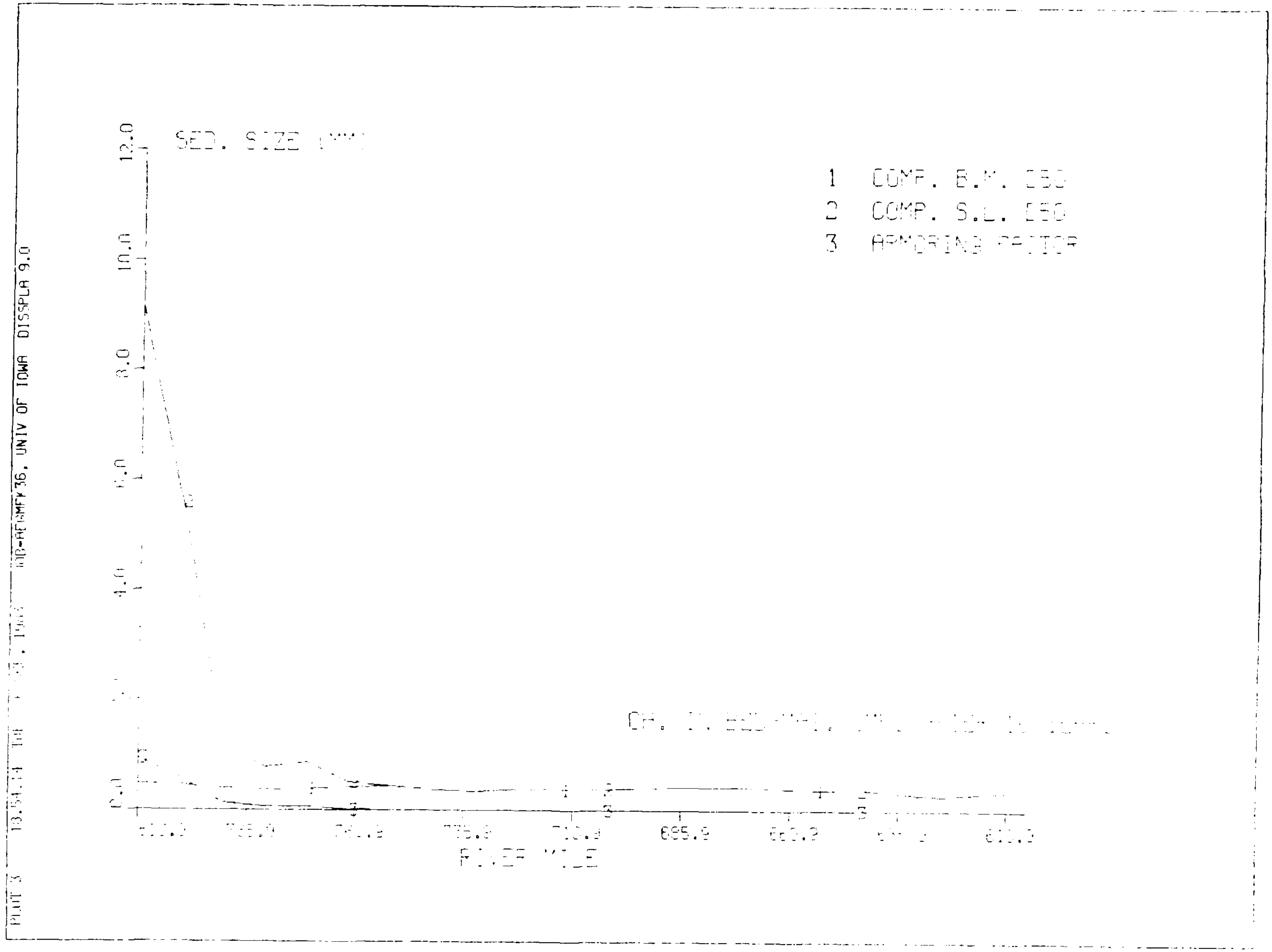


Figure 24. Change in bed-material composition for Run R2 after 16 years

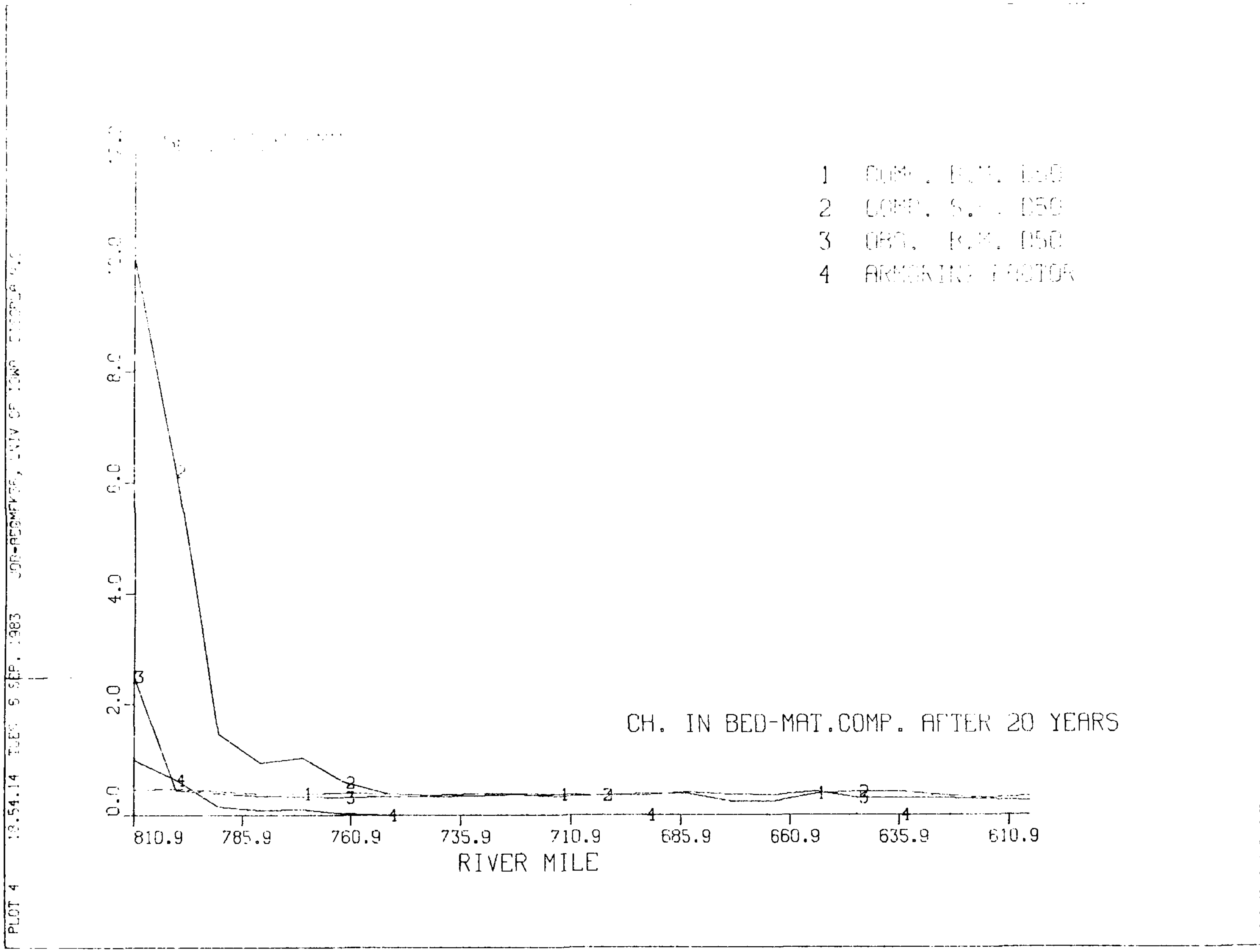


Figure 25. Change in bed-material composition for Run R2 after 20 years

These time intervals (3, 8, 16, and 20 years) are selected because changes in water-surface elevations were measured at these times; these observed values are also included in figures for comparison. For the remaining six runs, R3 through R8, the computed changes in bed and water-surface elevations after 20 years, and changes in D_{50} and ACF after 3, 8, 16, and 20 years of simulation, are presented in figures 26 through 55. It may be noted here the computed changes in water-suface elevations shown in these figures are calculated for a discharge of 36,000 cfs at the Gavins Point Dam. Finally, the computed temporal evolutions of the bed-elevation changes for all eight runs, R1 through R8, are shown in figures 56 through 63 at 5 locations: RM 810.9 (Gavins Point Dam), RM 752.4 (Ponca), RM 732.3 (Sioux City), RM 693.9 (Decatur), and RM 615.9 (Omaha). A comparison of the results among different simulation runs, and with the corresponding observed values where available, is presented in the next section.

D. Comparison and Discussion of Results

The results presented in the preceeding section are evaluated by comparison with the observed changes in water-surface elevations (Δh) for Q = 29,500 cfs at Yankton, and the observed mean bed-material size (D_{50}) at different locations along the study reach, shown in figures 64 and 65, respectively. It is seen in figure 64 that the decline in water-surface elevation for the period 1957-77 decreases from about 5.5 ft at Gavins Point Dam to about 2.5 ft at RM 790.0, then increases to about 8 ft at RM 725.0 (near Sioux City, RM 732.9), and again decreases to 0 ft at RM 642.0 (near Blair); from there to Omaha a rise in water-surface elevation of about 1.5 ft is observed. Significant bed-material coarsening, from about 0.24 - 0.40 mm

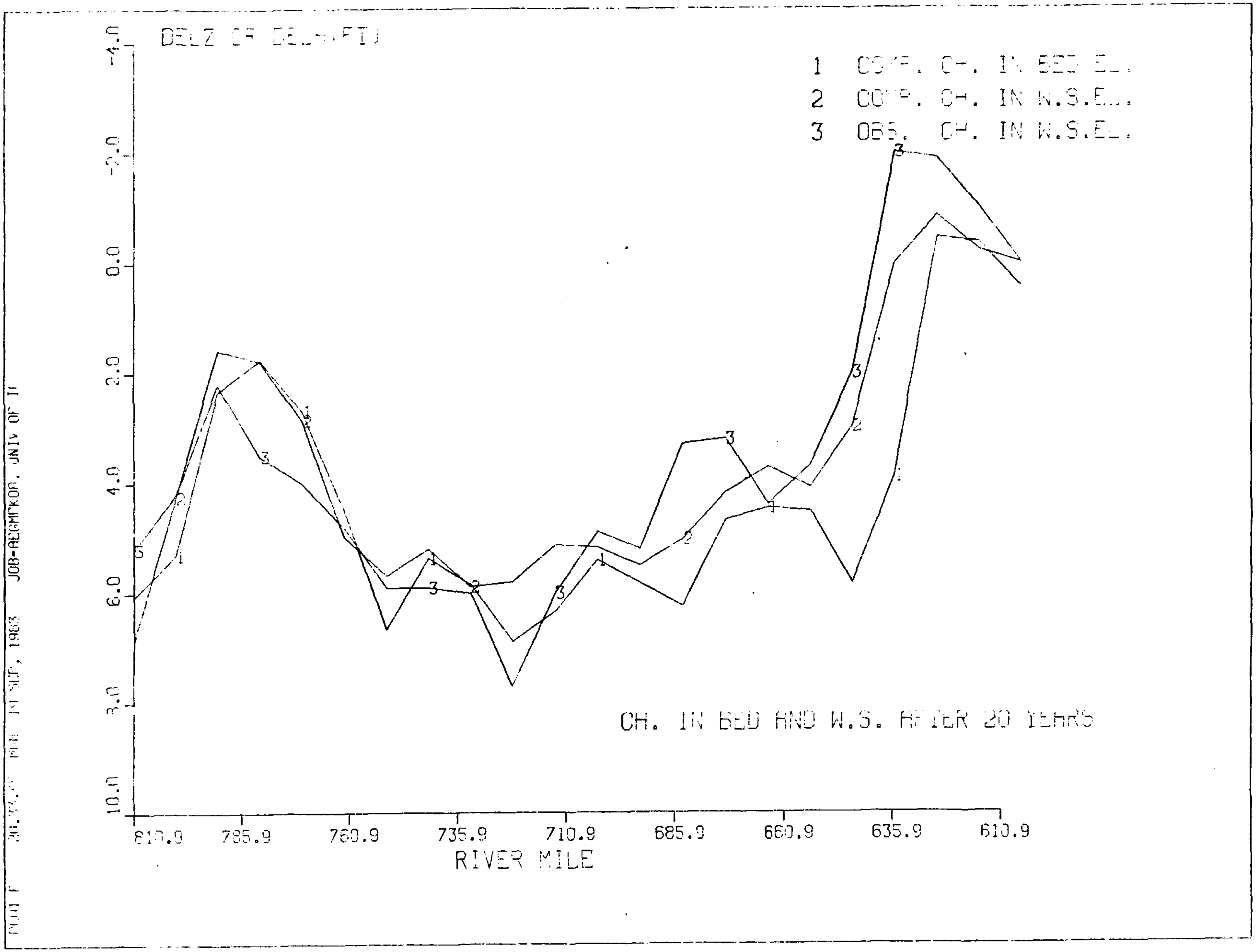


Figure 26. Change in bed and water-surface elevations for Run R3 after 20 years

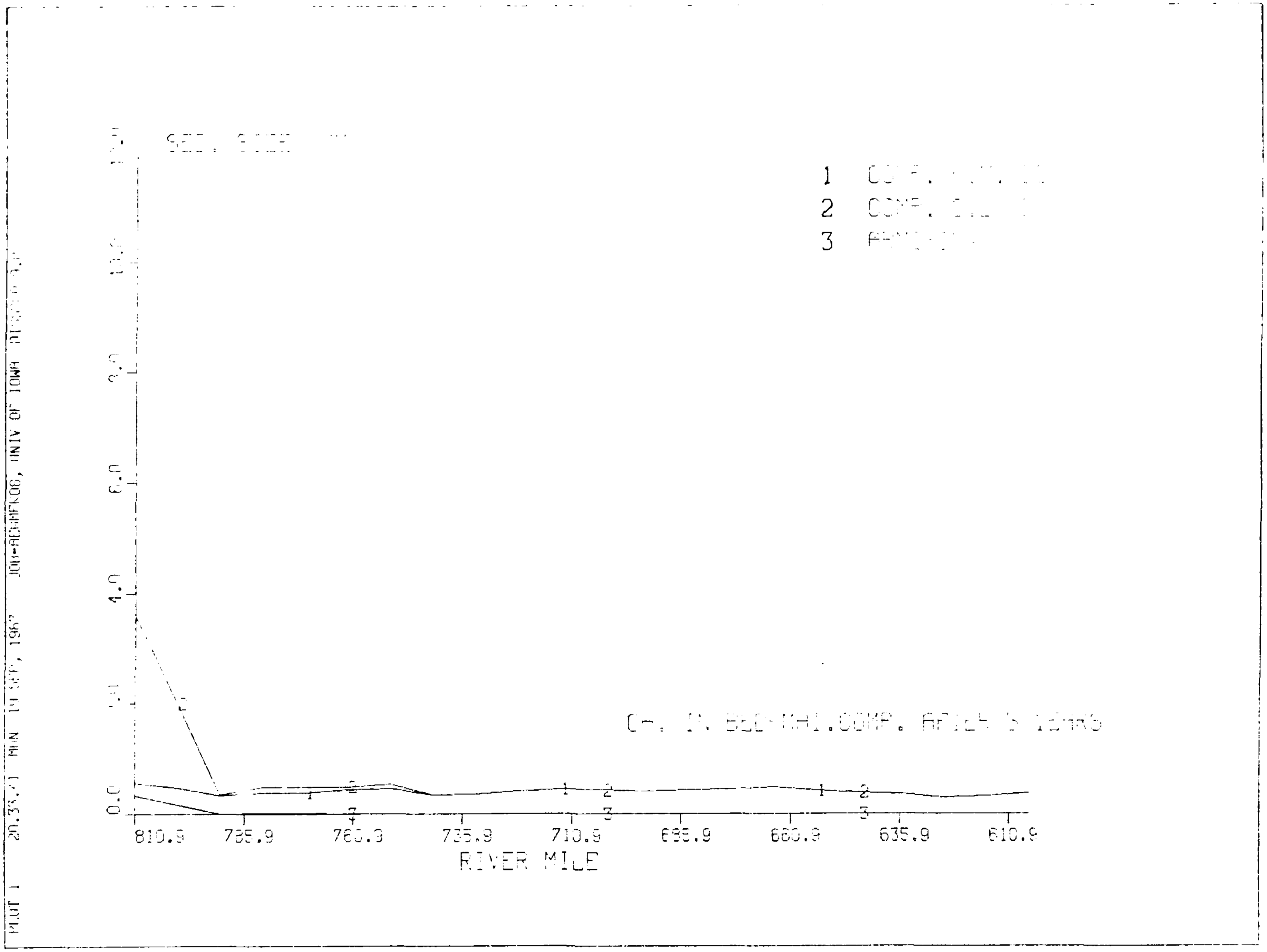


Figure 27. Change in bed-material composition for Run R3 after 3 years

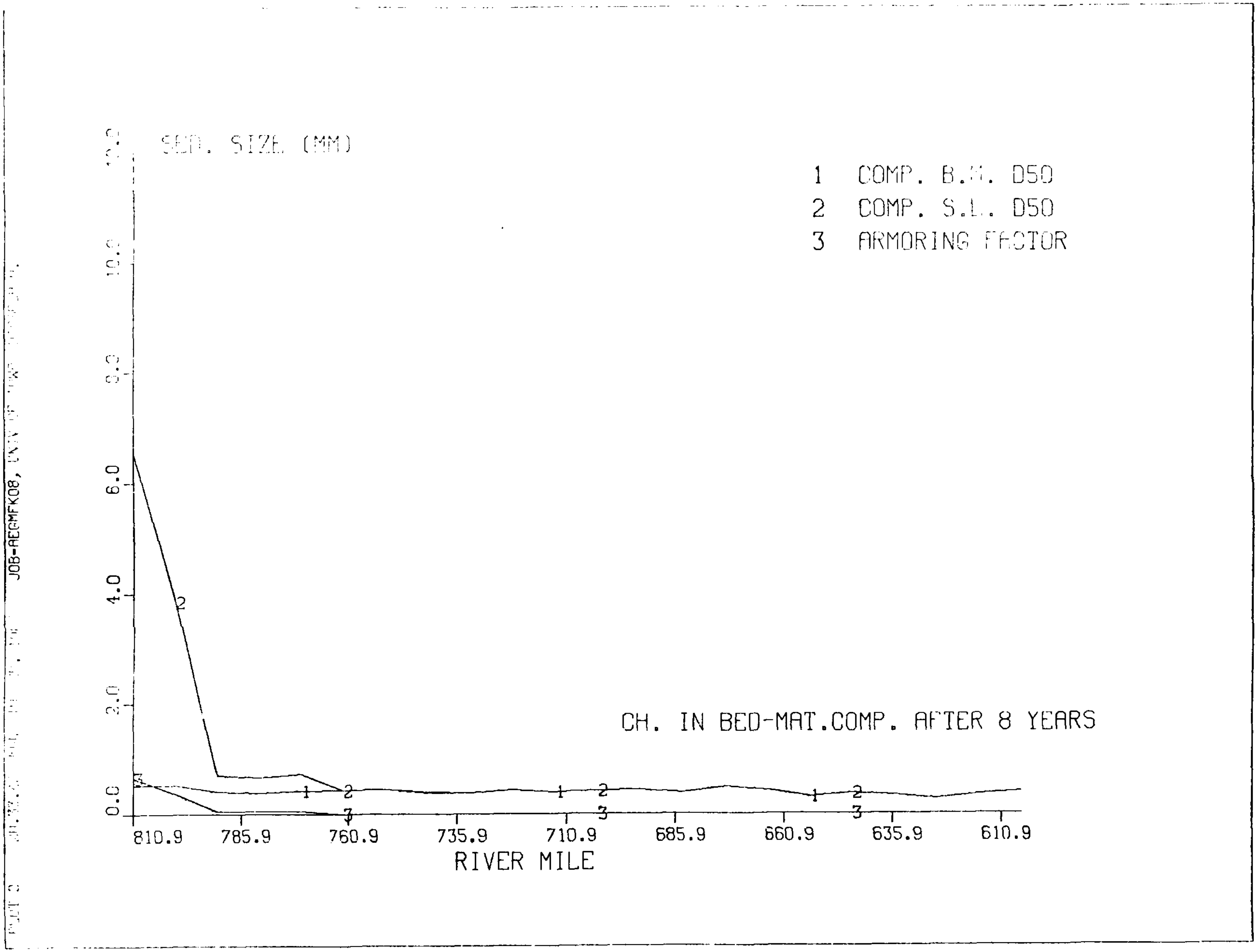


Figure 28. Change in bed-material composition for Run R3 after 8 years

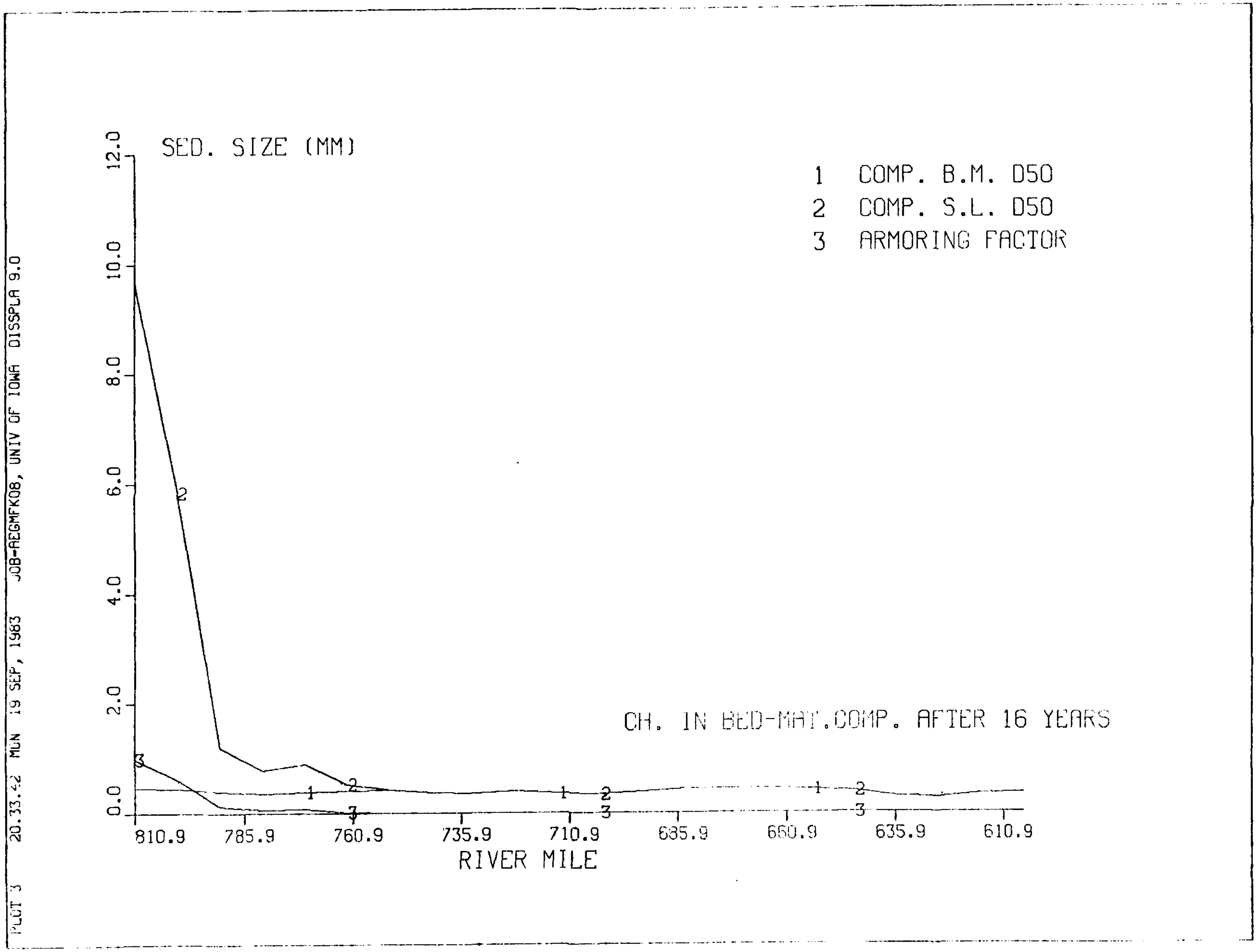


Figure 29. Change in bed-material composition for Run R3 after 16 years

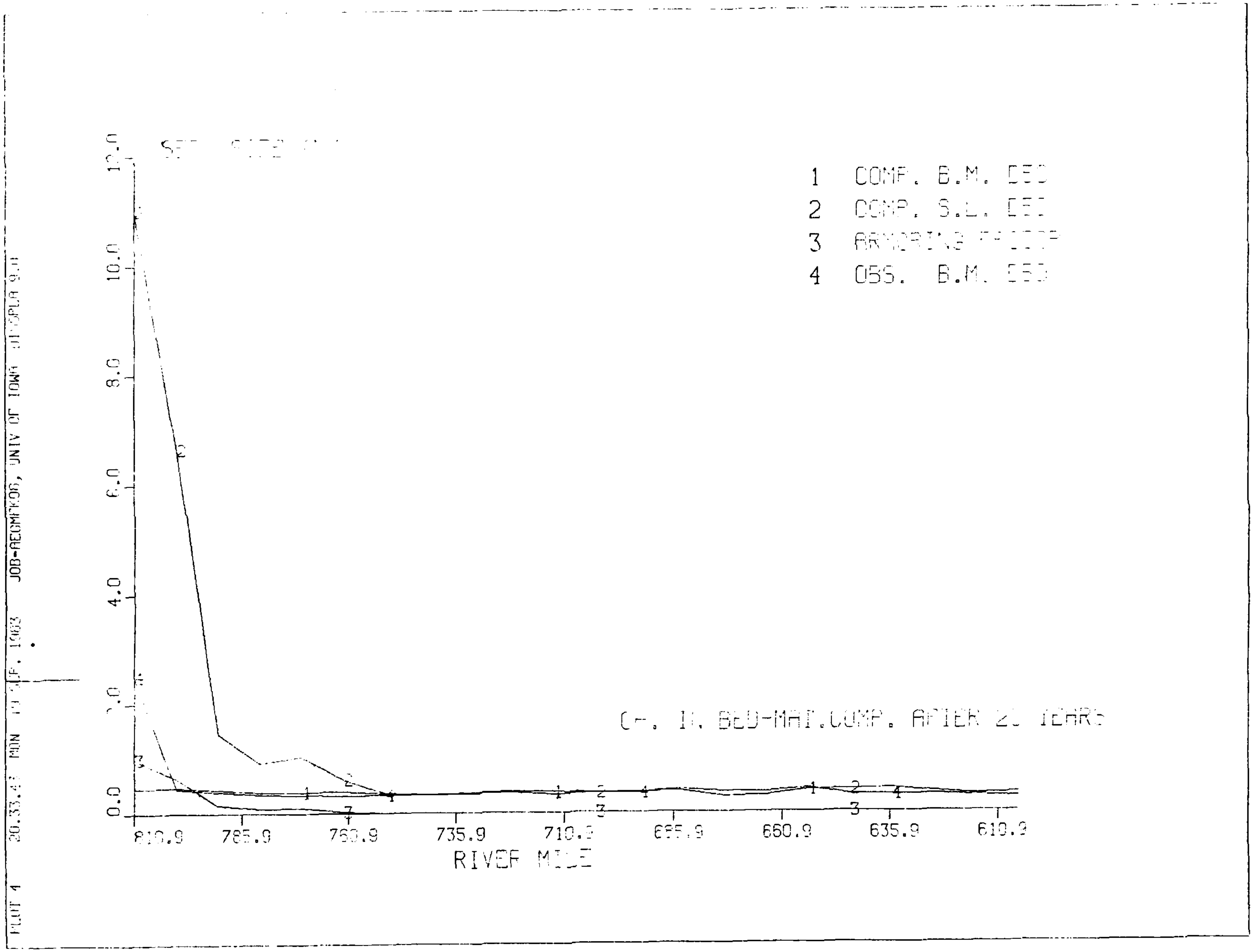


Figure 30. Change in bed-material composition for Run R3 after 20 years

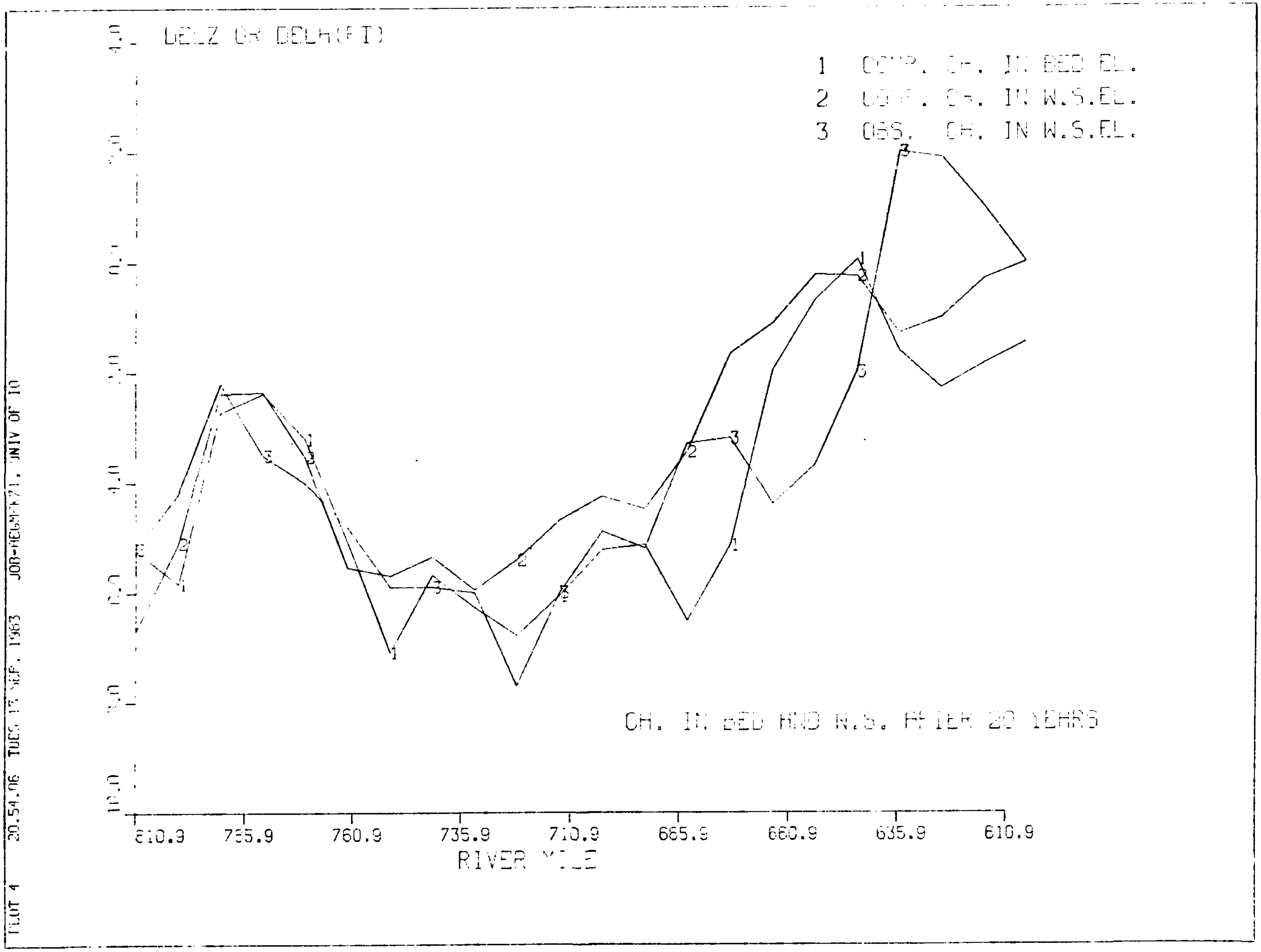


Figure 31. Change in bed and water-surface elevations for Run R4 after 20 years

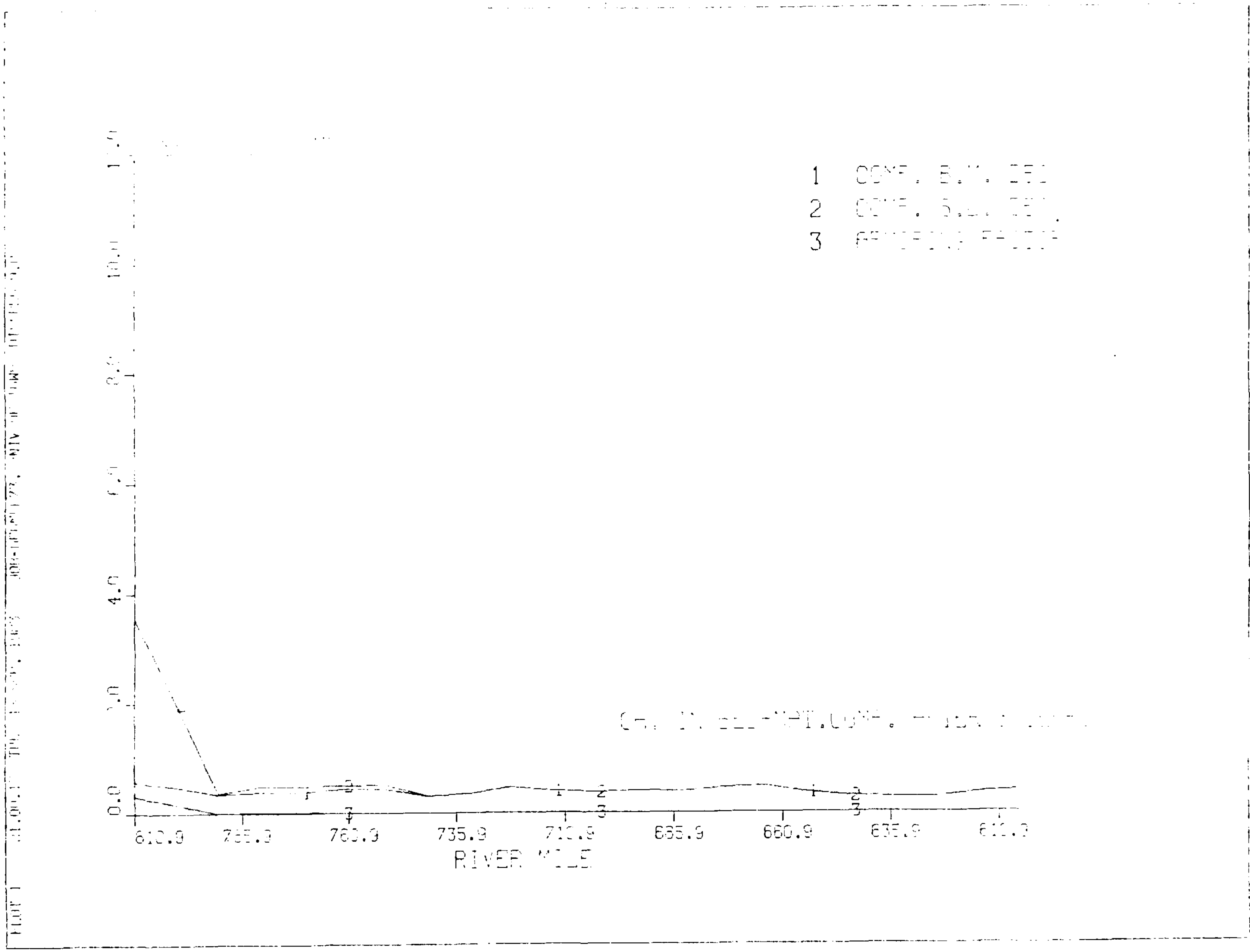


Figure 32. Change in bed-material composition for Run R4 after 3 years

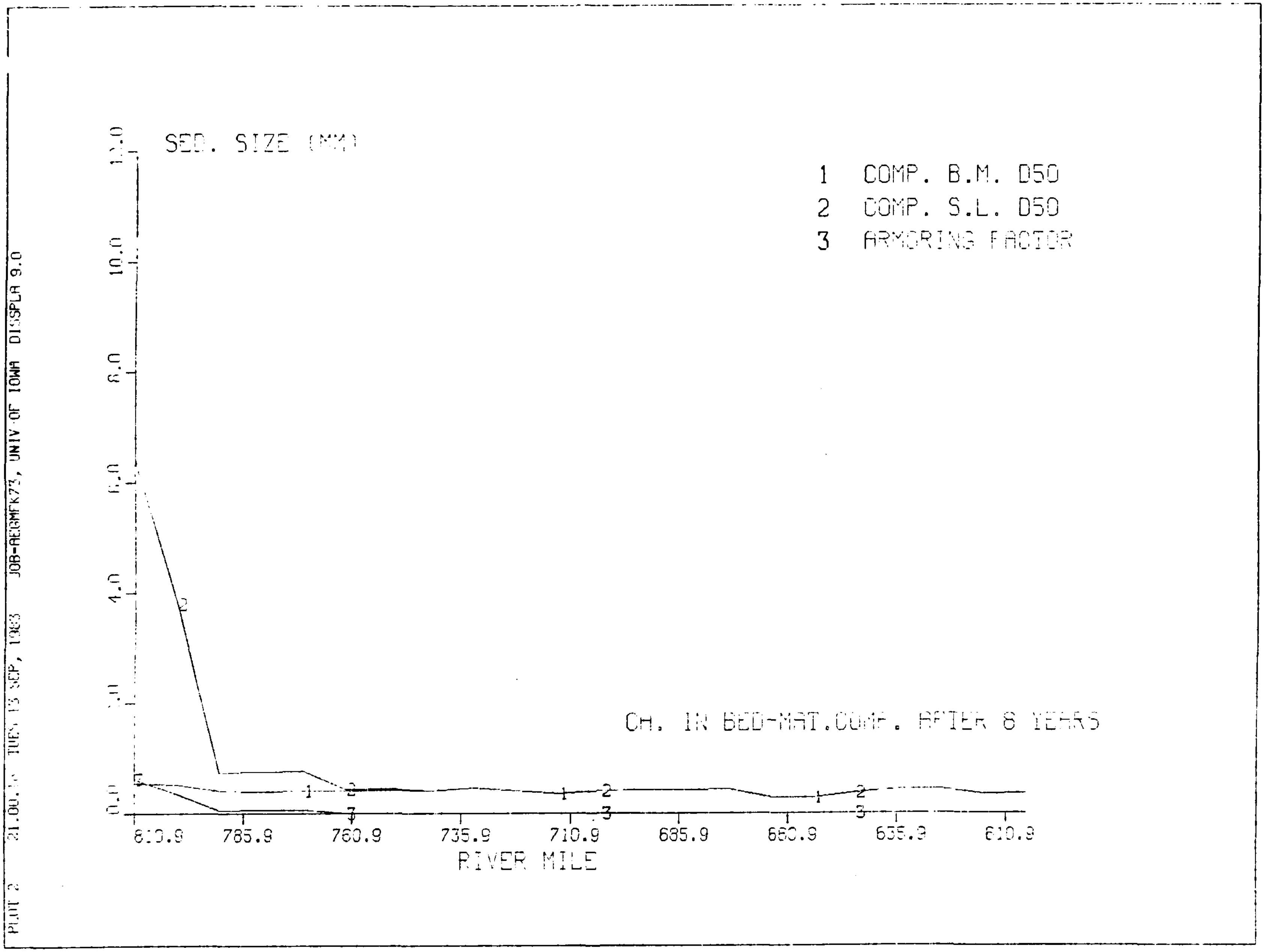


Figure 33. Change in bed-material composition for Run R4 after 8 years

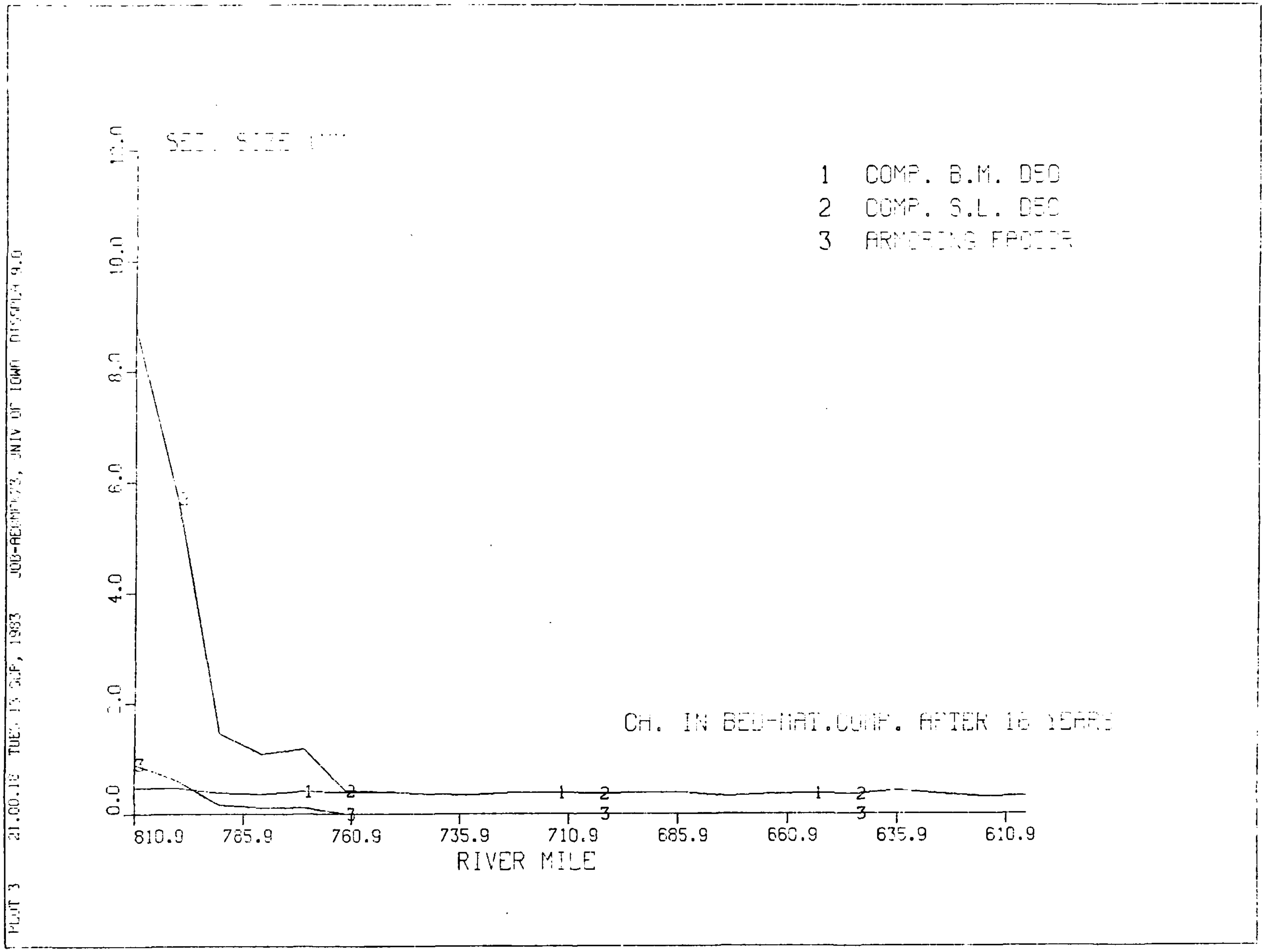


Figure 34. Change in bed-material composition for Run R4 after 16 years

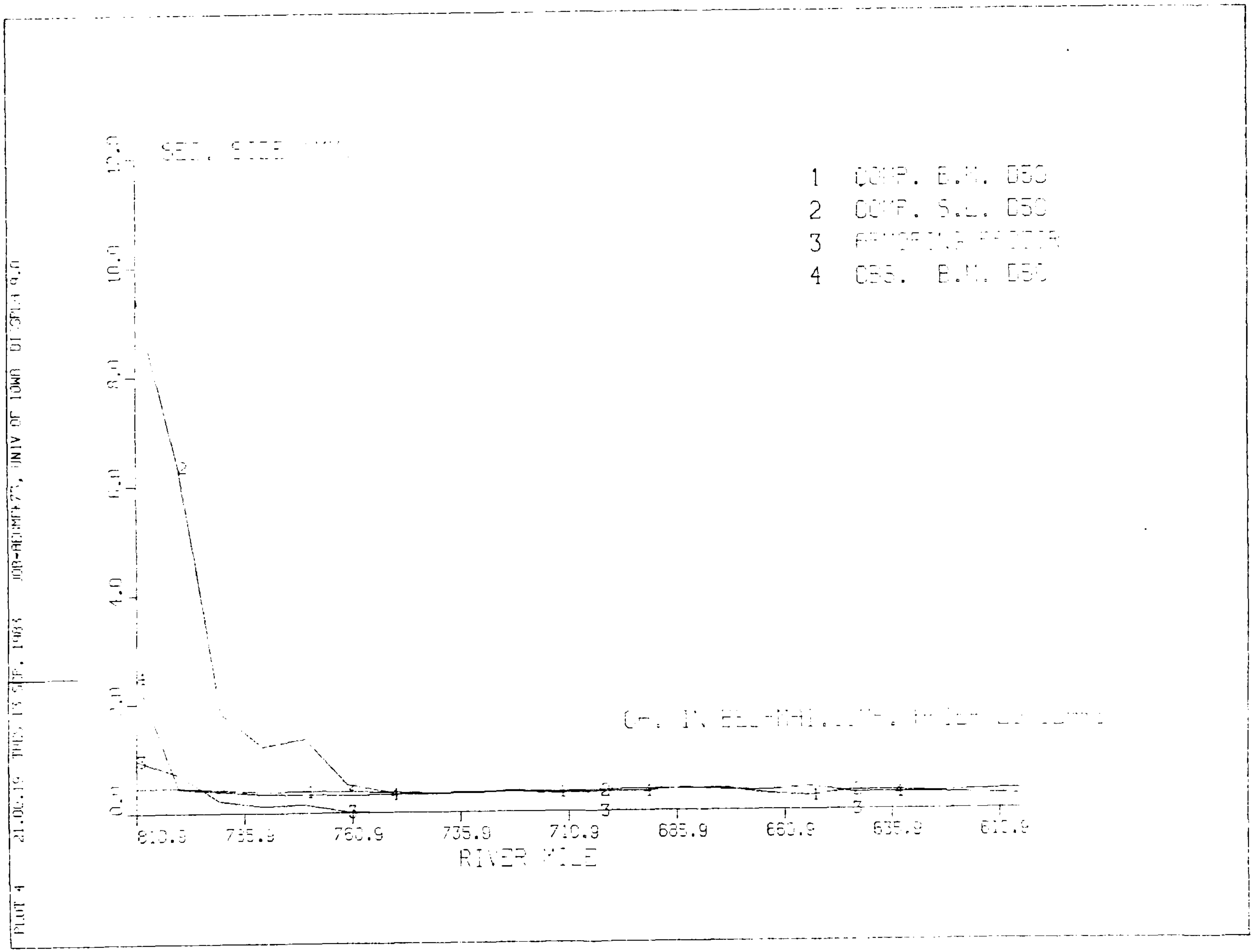


Figure 35. Change in bed-material composition for Run R4 after 20 years

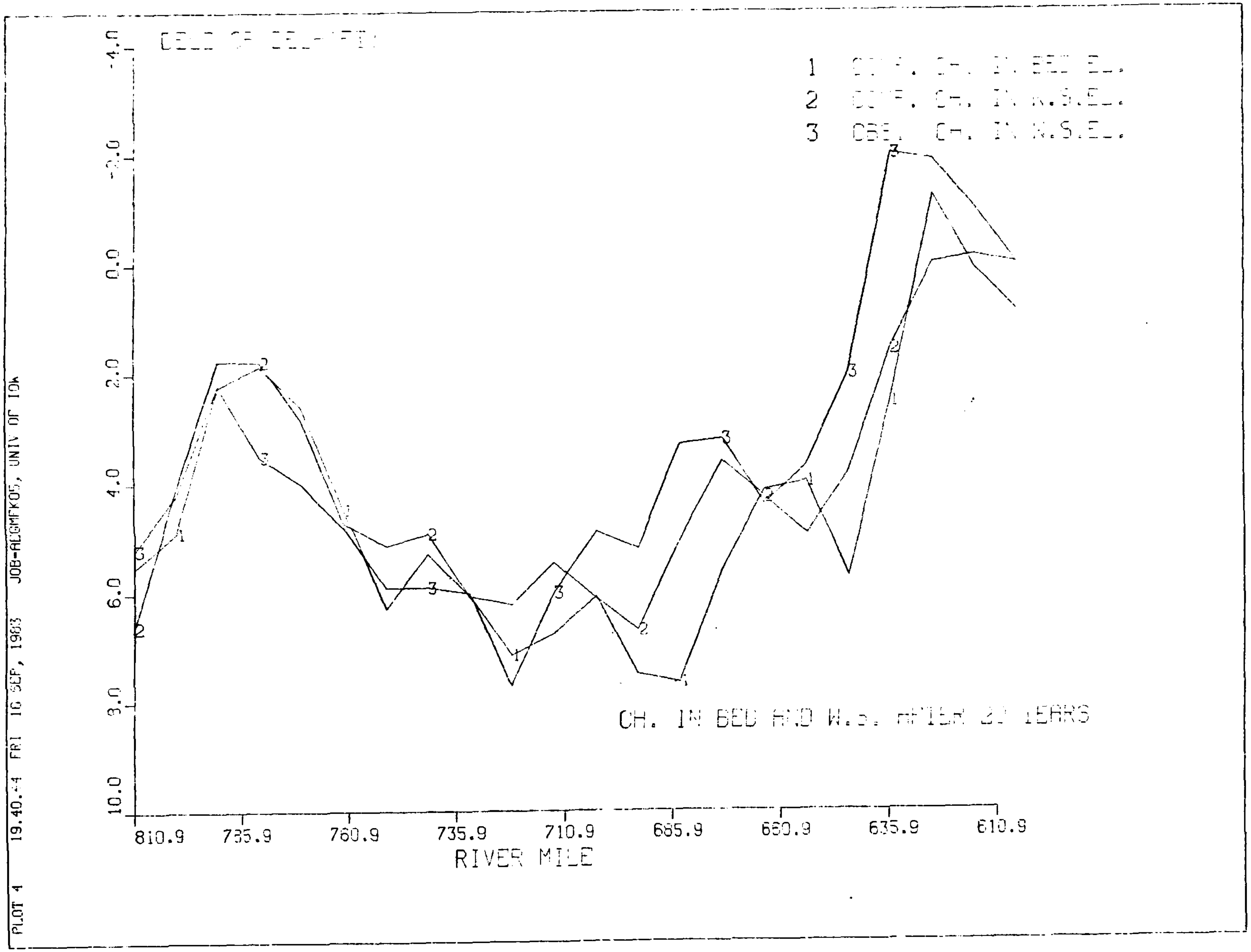


Figure 36. Change in bed and water-surface elevations for Run R5 after 20 years

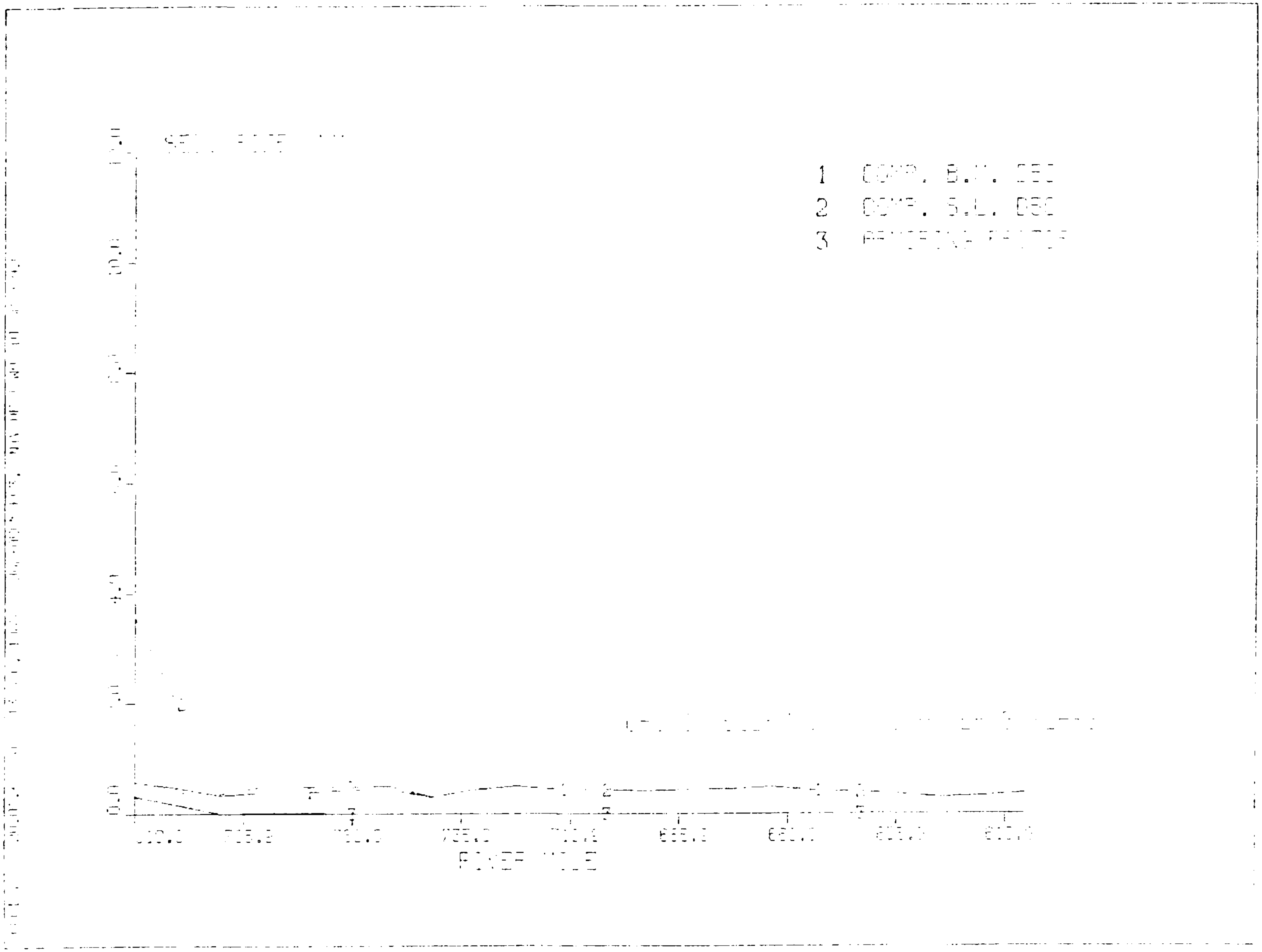


Figure 37. Change in bed-material composition for Run R5 after 3 years

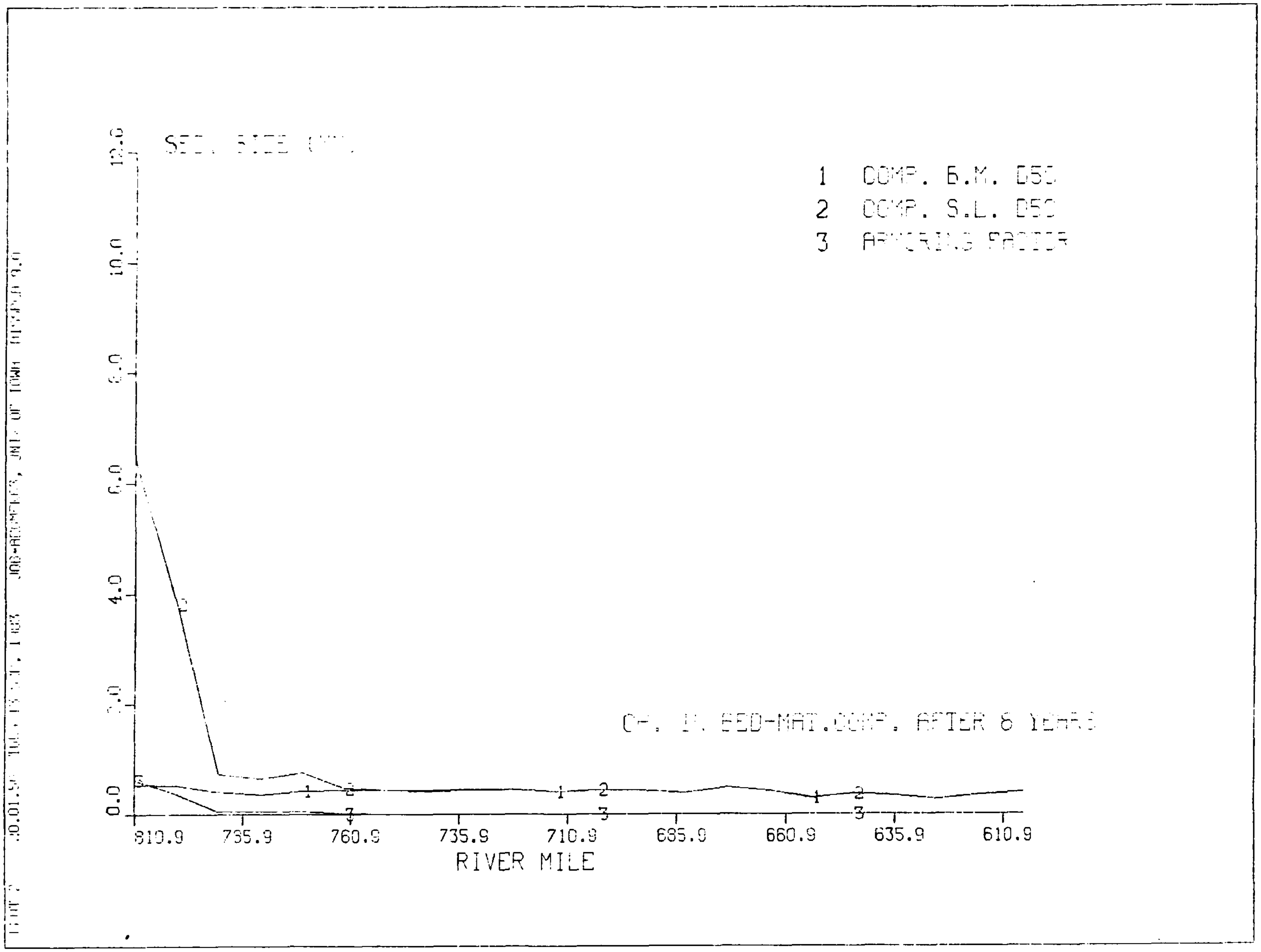


Figure 38. Change in bed-material composition for Run R5 after 8 years

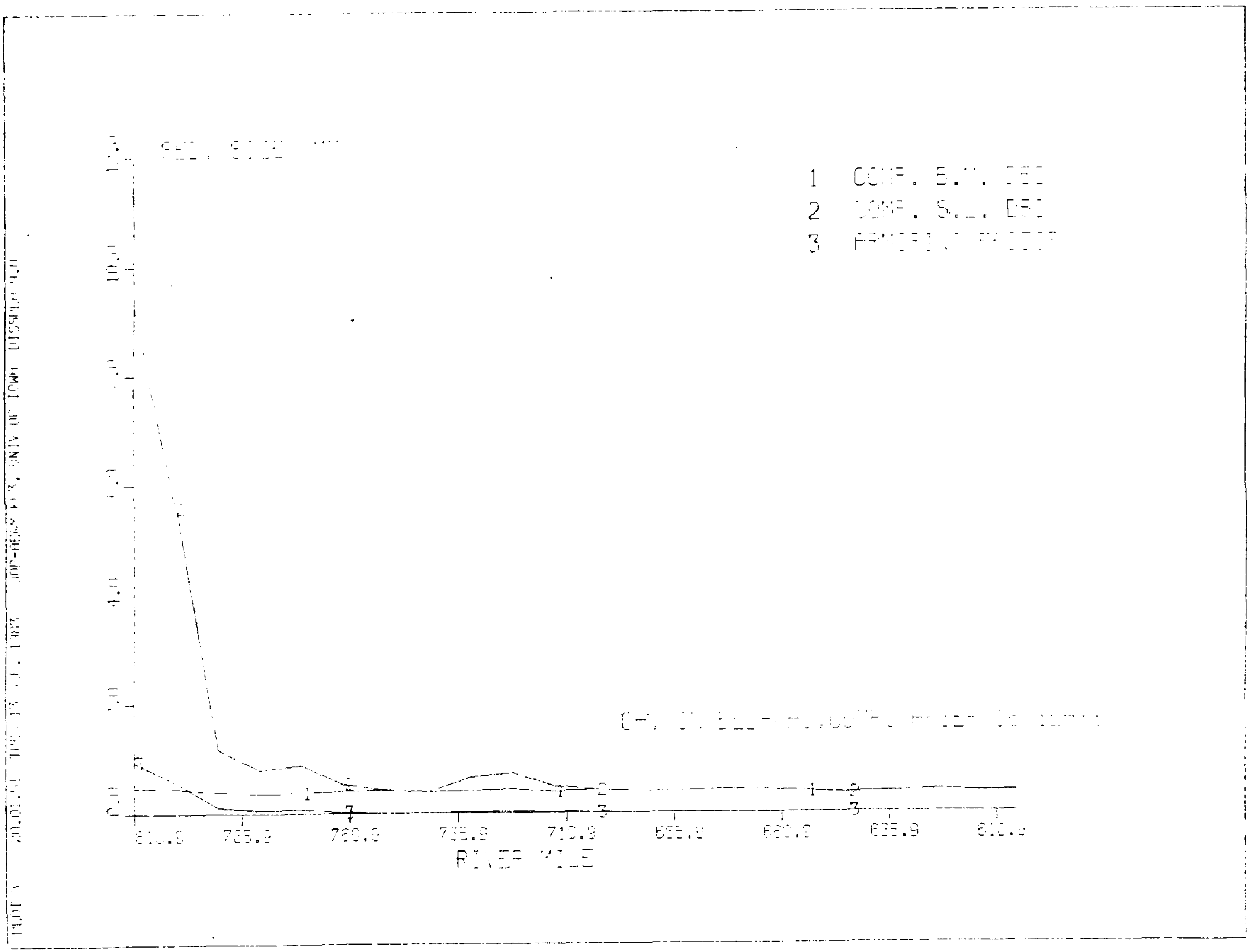


Figure 39. Change in bed-material composition for Run R5 after 16 years

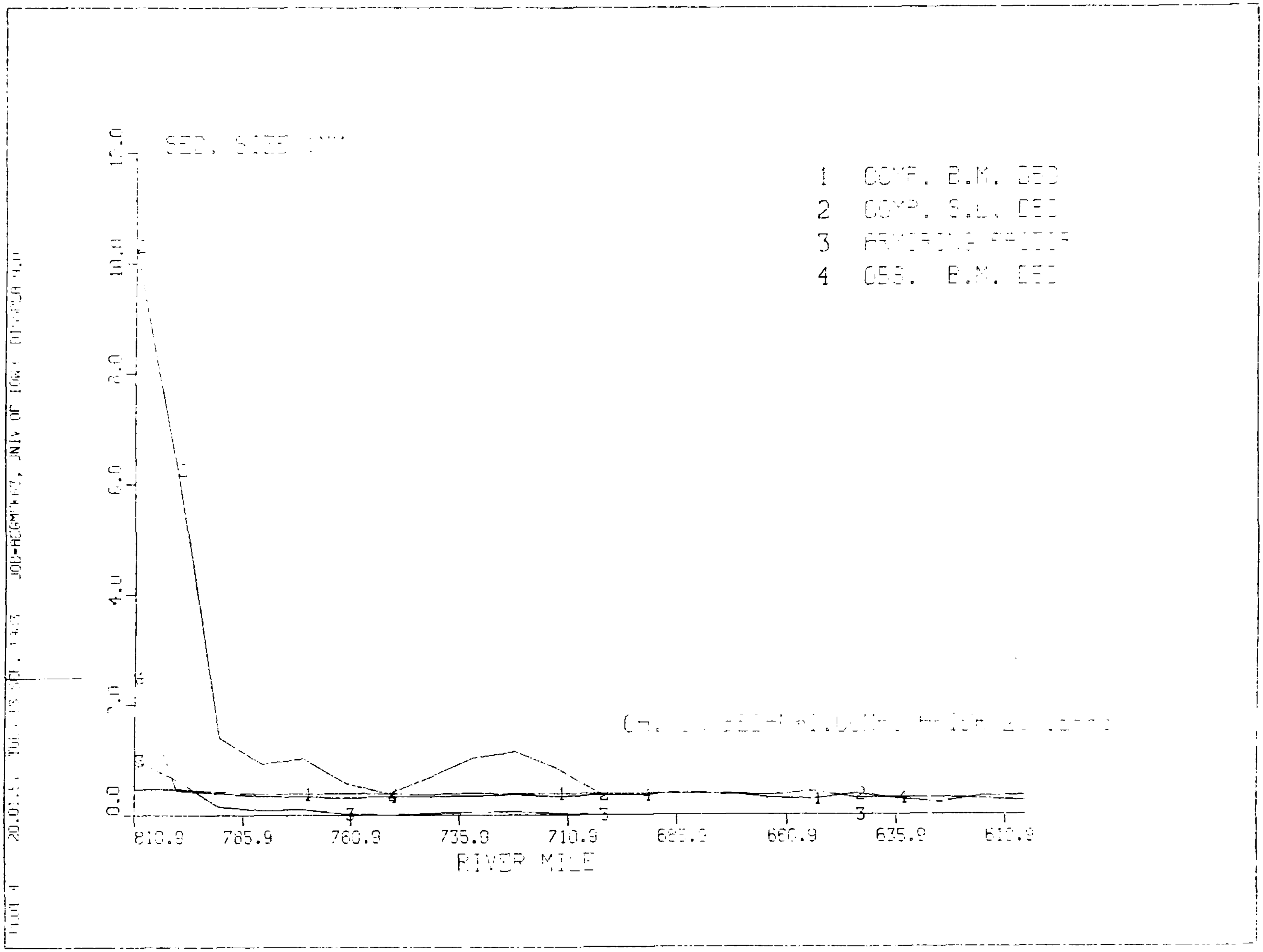


Figure 40. Change in bed-material composition for Run R5 after 20 years

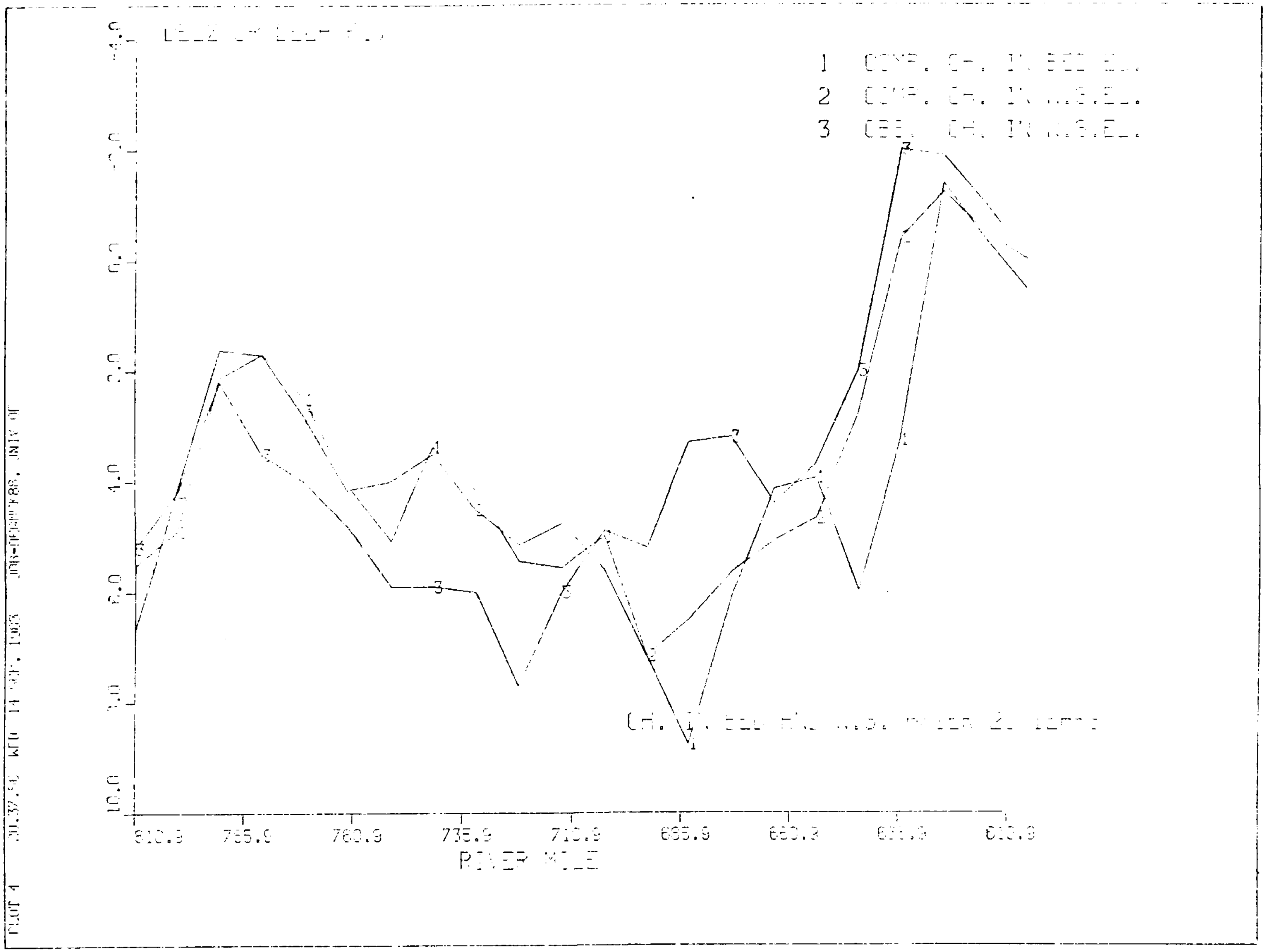


Figure 41. Change in bed and water-surface elevations for Run R6 after 20 years

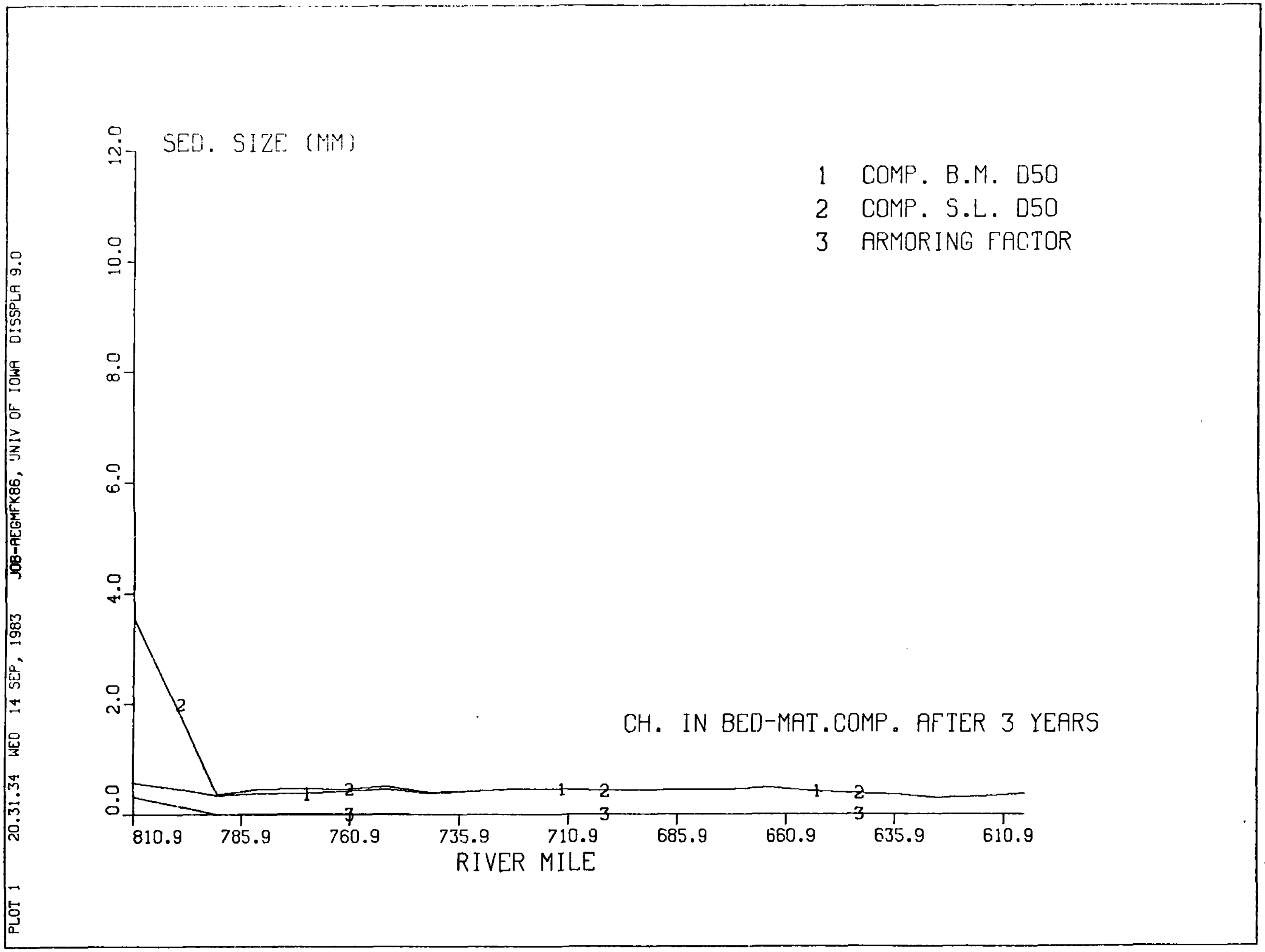


Figure 42. Change in bed-material composition for Run R6 after 3 years

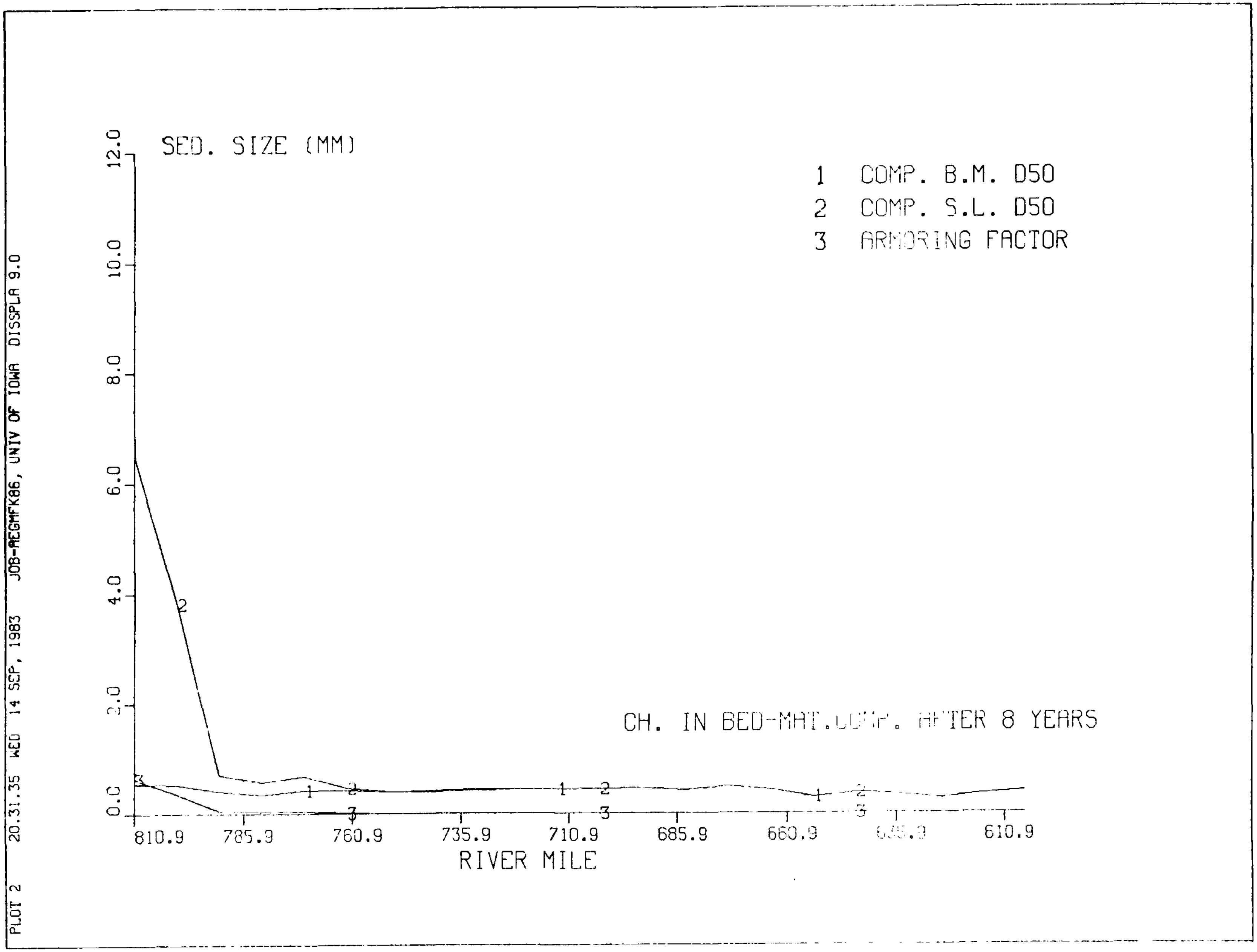


Figure 43. Change in bed-material composition for Run R6 after 8 years

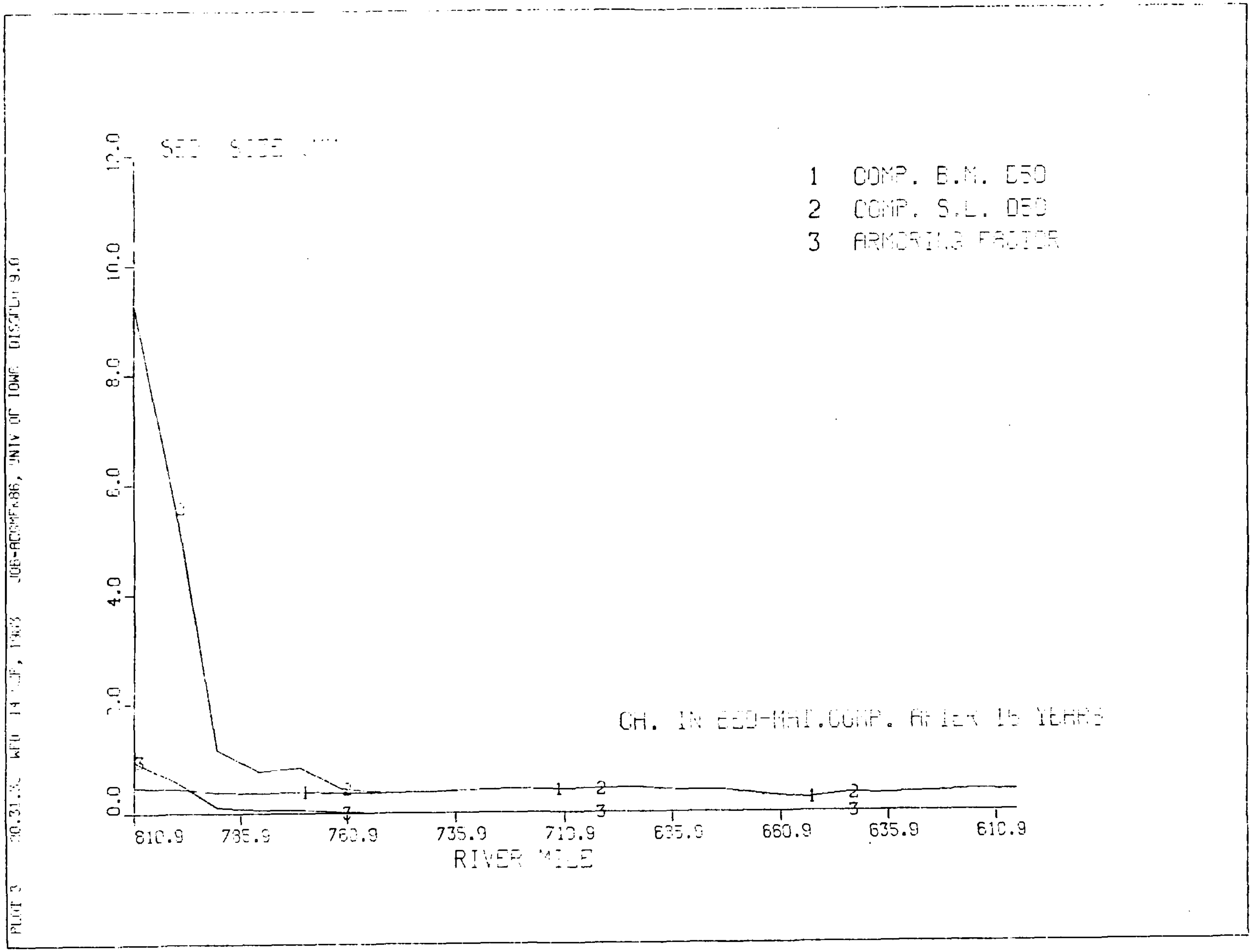


Figure 44. Change in bed-material composition for Run R6 after 16 years

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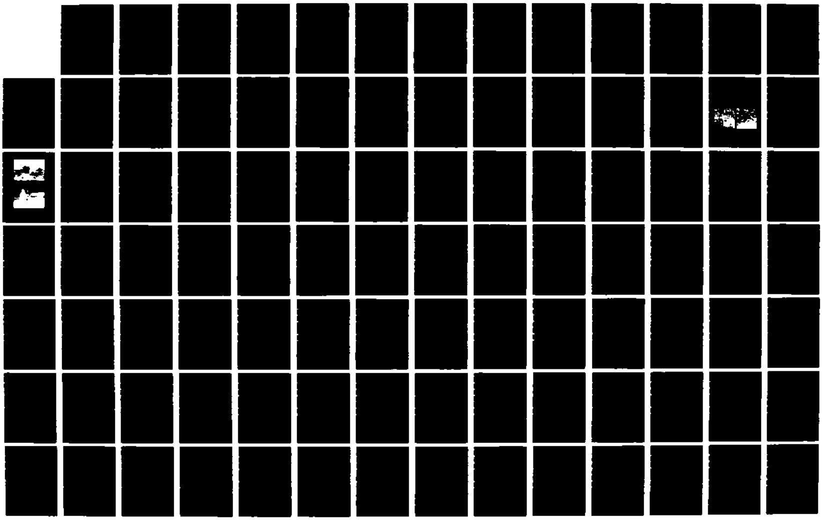

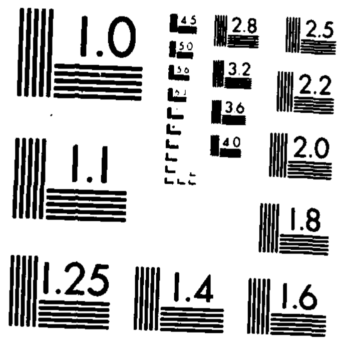

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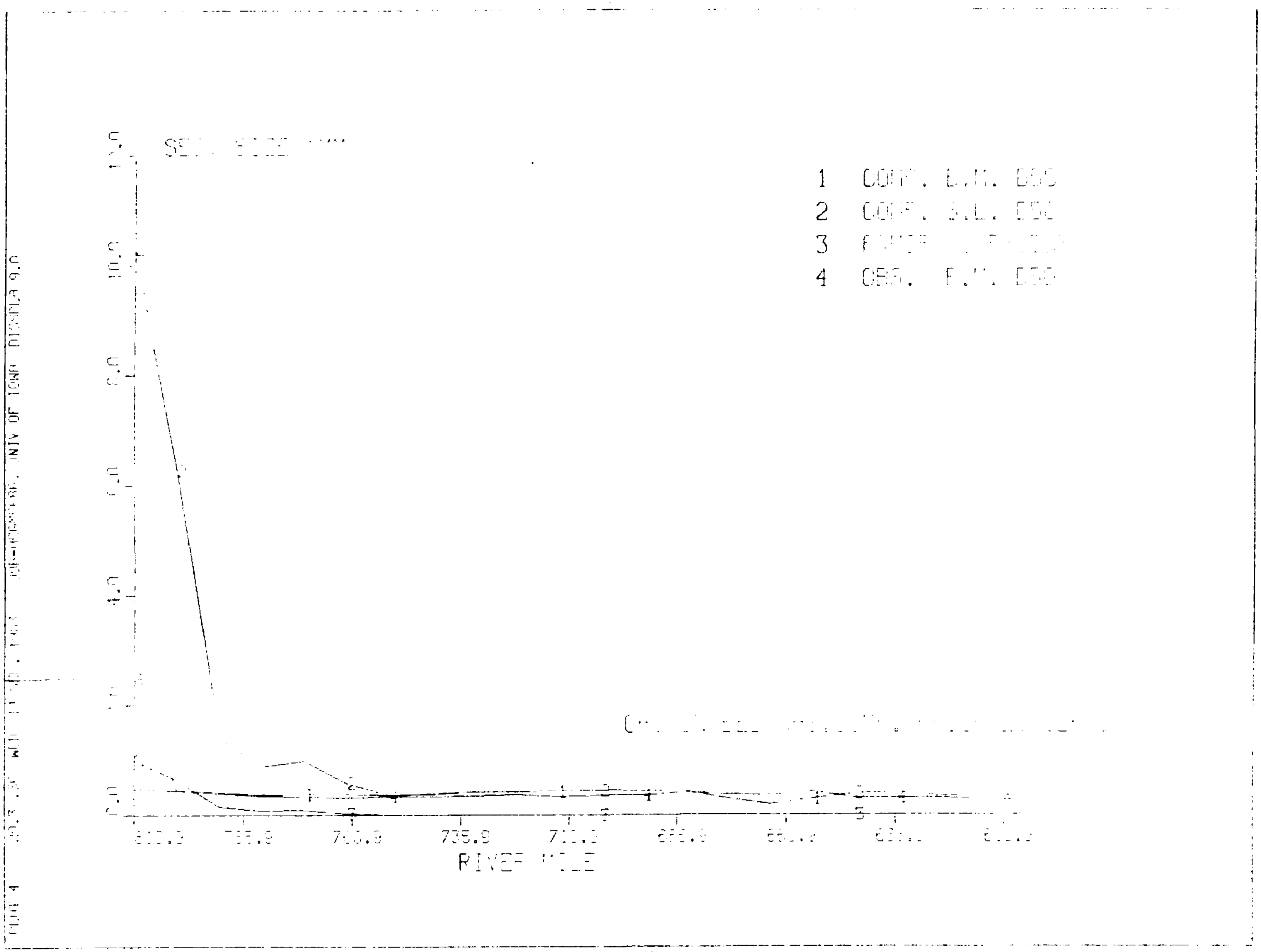


Figure 45. Change in bed-material composition for Run R6 after 20 years

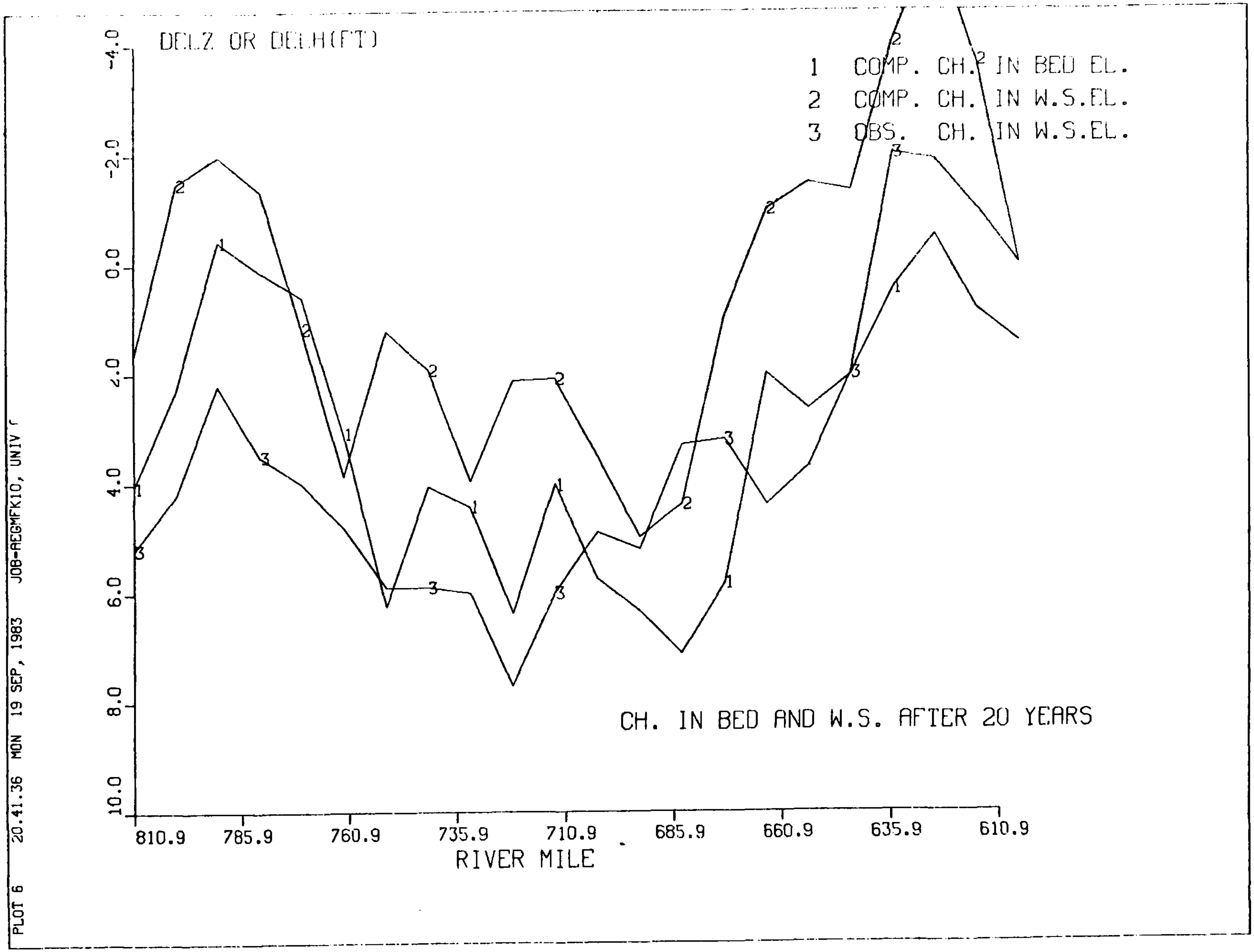


Figure 46. Change in bed and water-surface elevations for Run R7 after 20 years

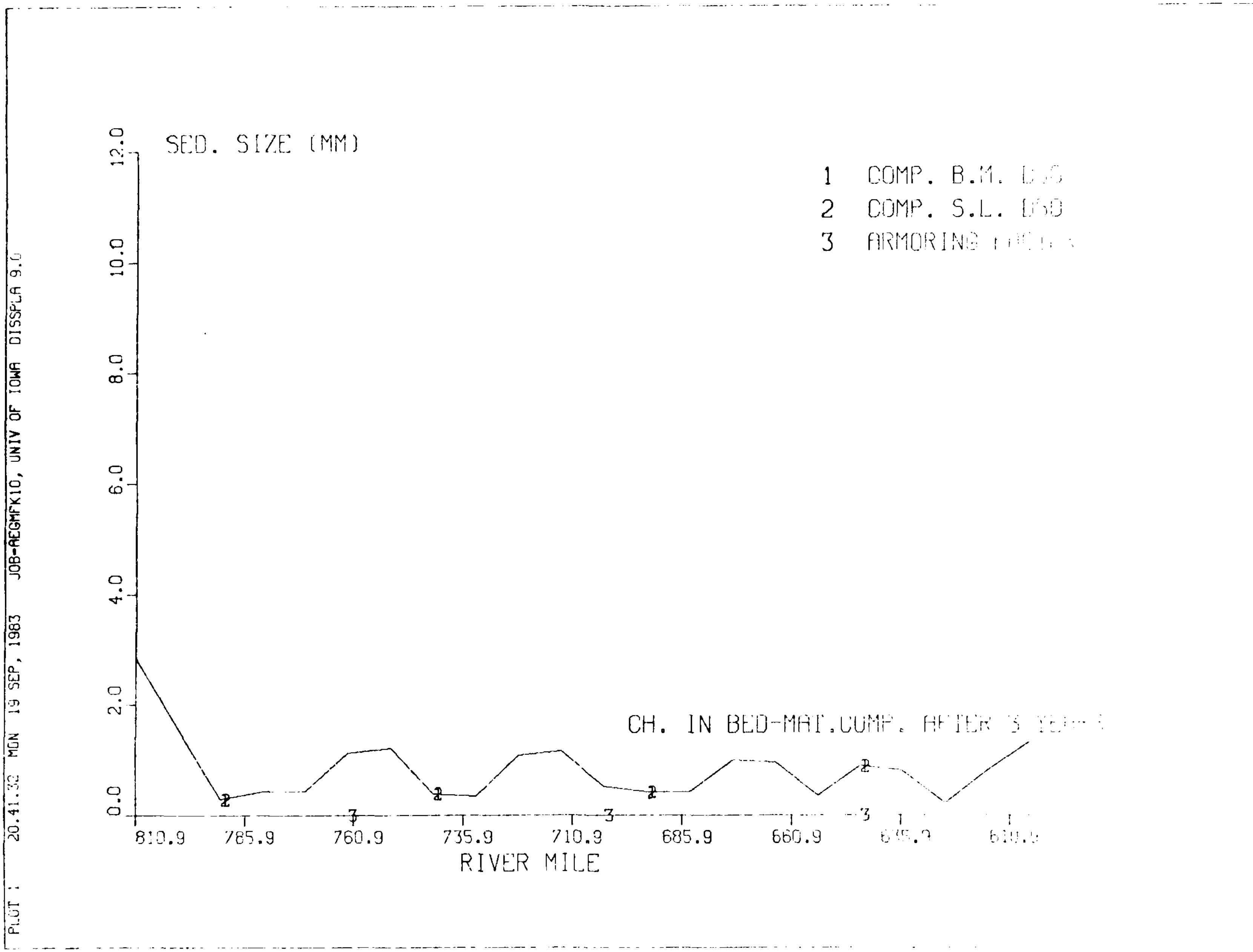


Figure 47. Change in bed-material composition for Run R7 after 3 years

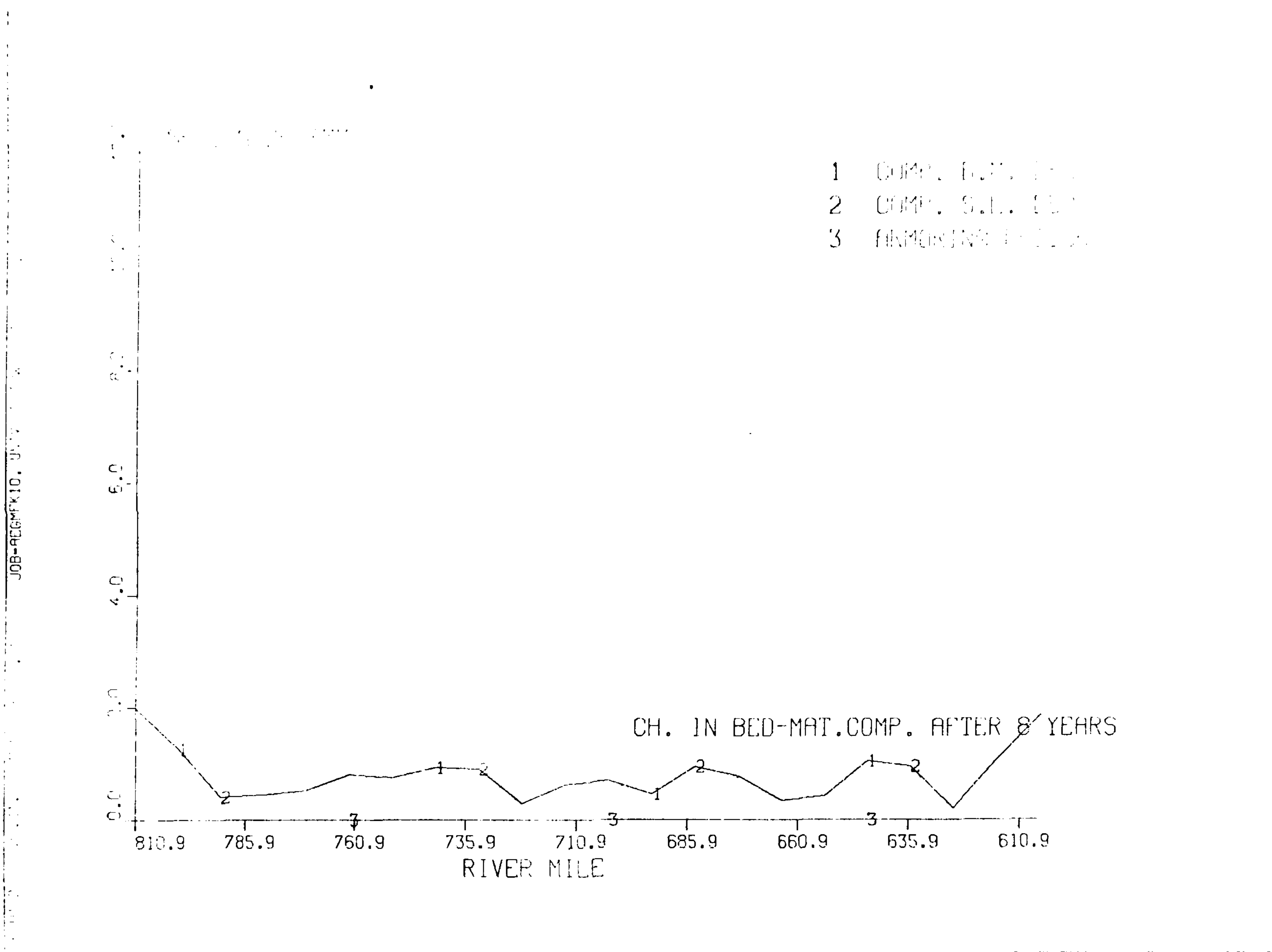


Figure 48. Change in bed-material composition for Run R7 after 8 years

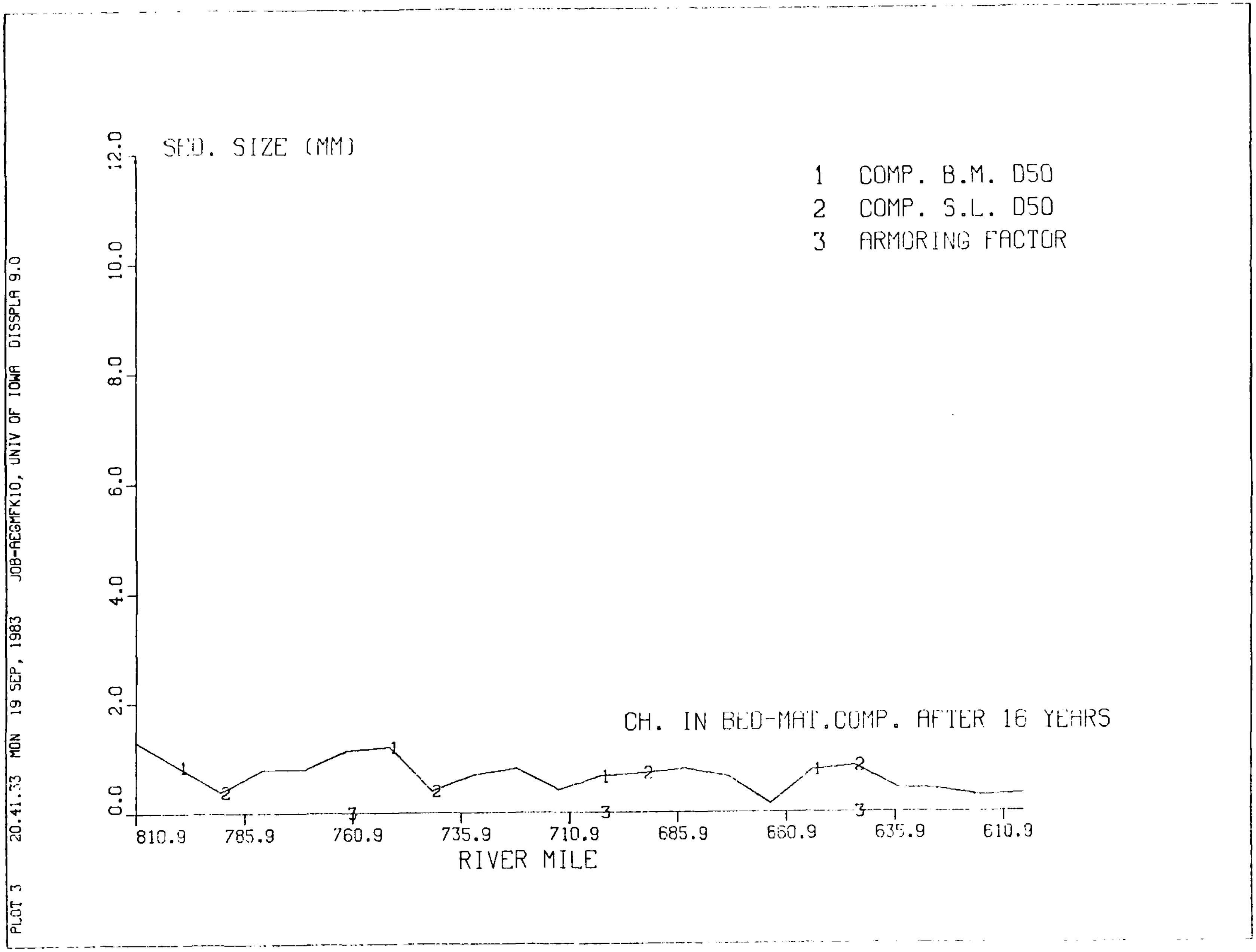


Figure 49. Change in bed-material composition for Run R7 after 16 years

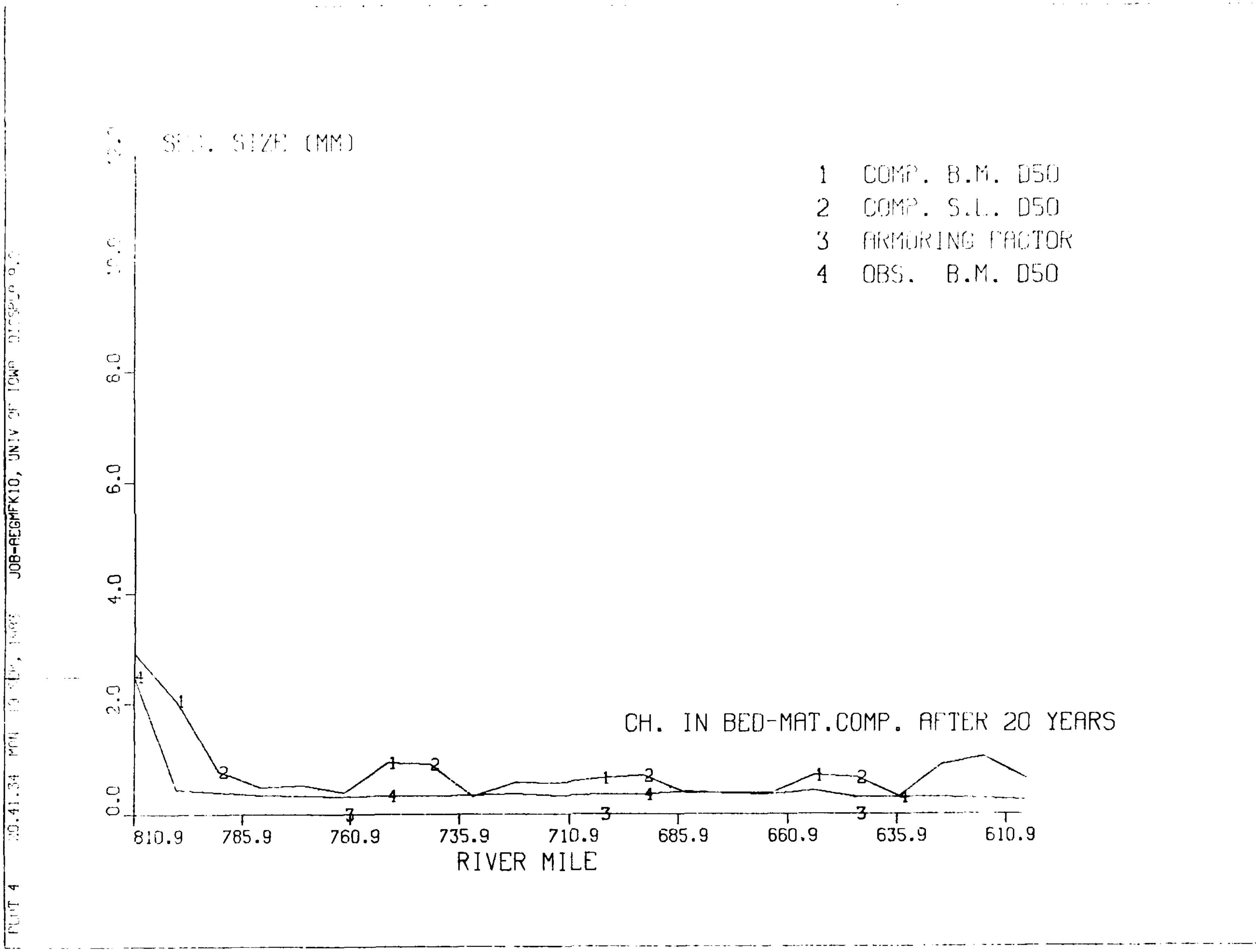


Figure 50. Change in bed-material composition for Run R7 after 20 years

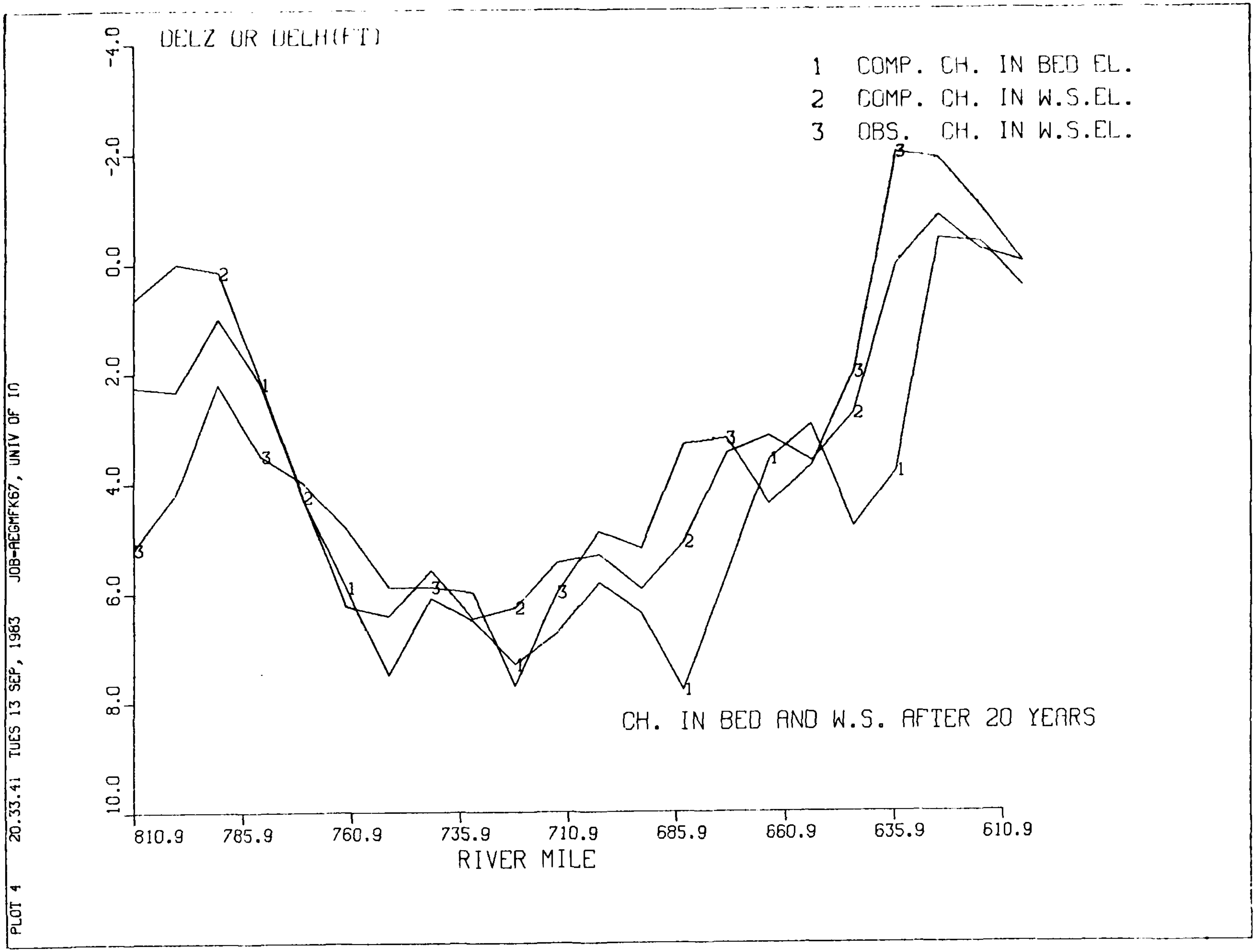


Figure 51. Change in bed and water-surface elevations for Run R8 after 20 years

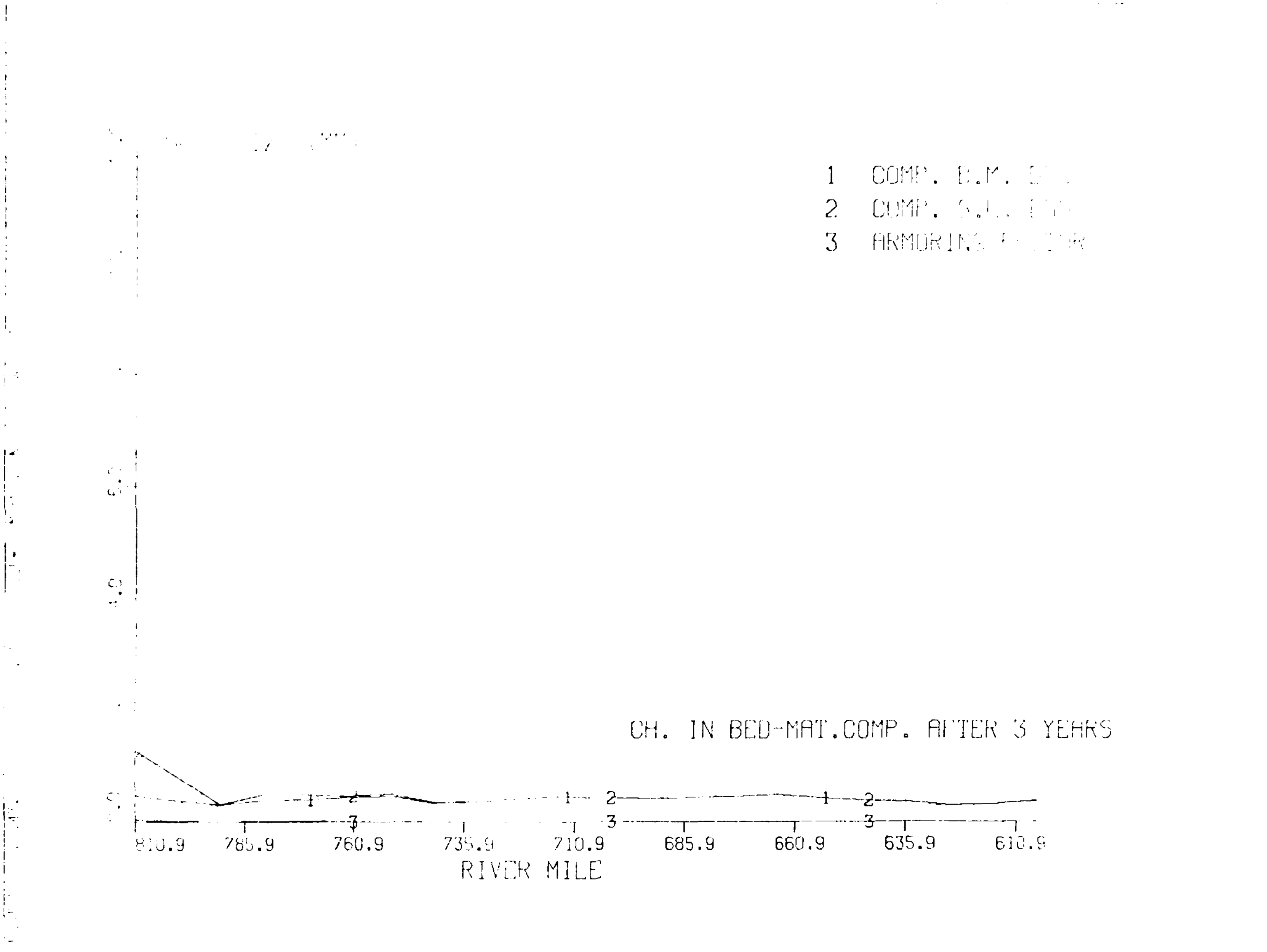


Figure 52. Change in bed-material composition for Run R8 after 3 years

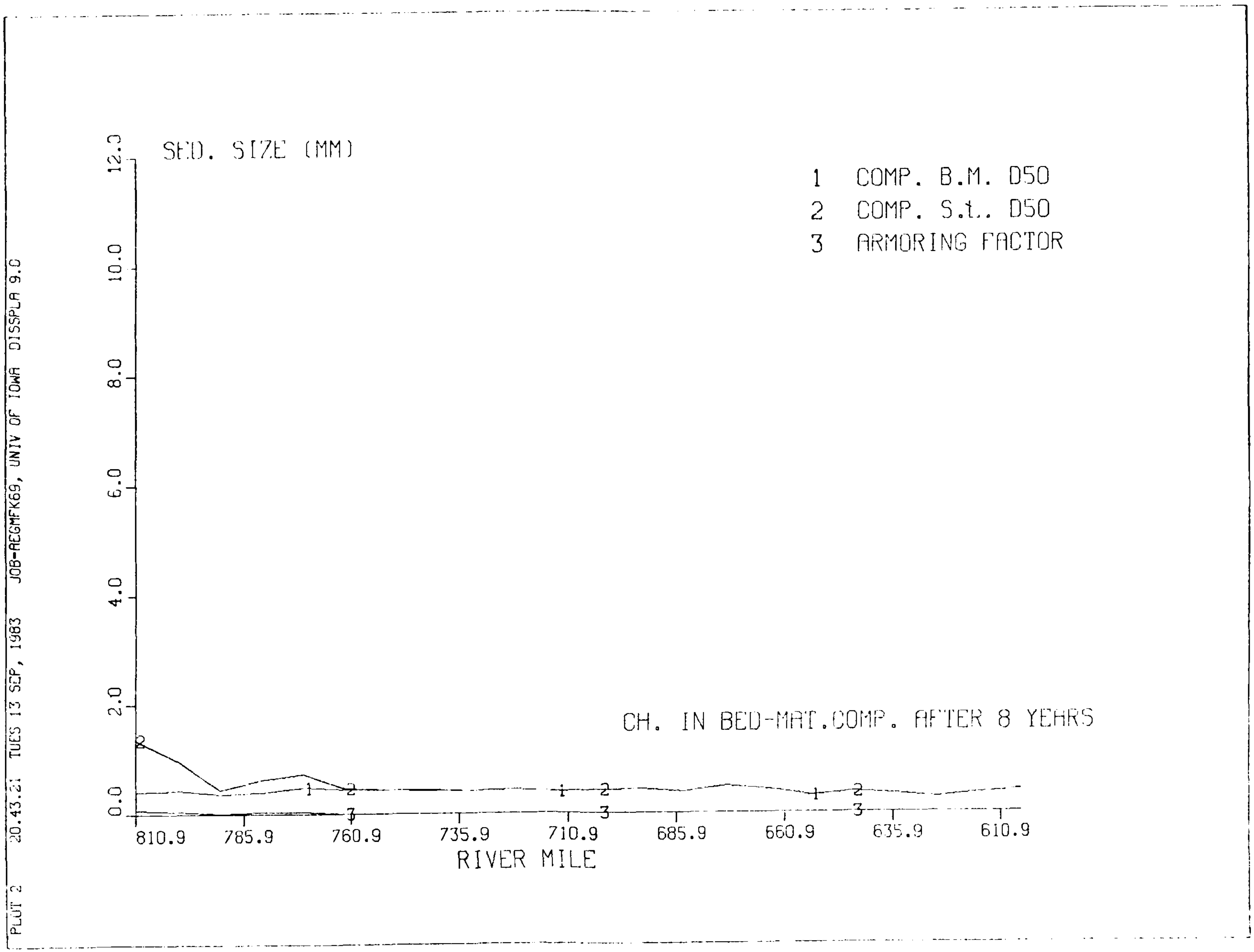


Figure 53. Change in bed-material composition for Run R8 after 8 years

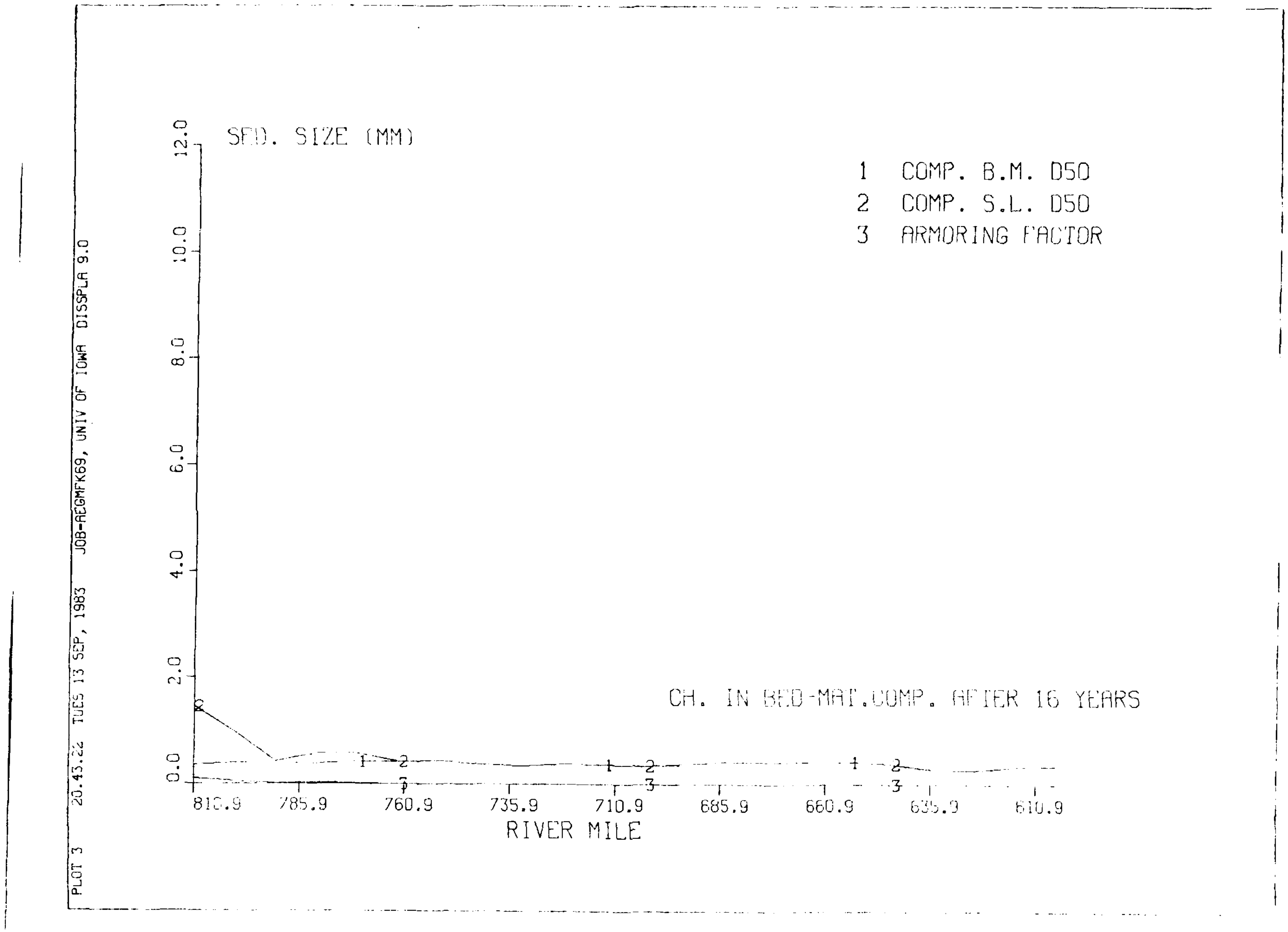


Figure 54. Change in bed-material composition for Run R8 after 16 years

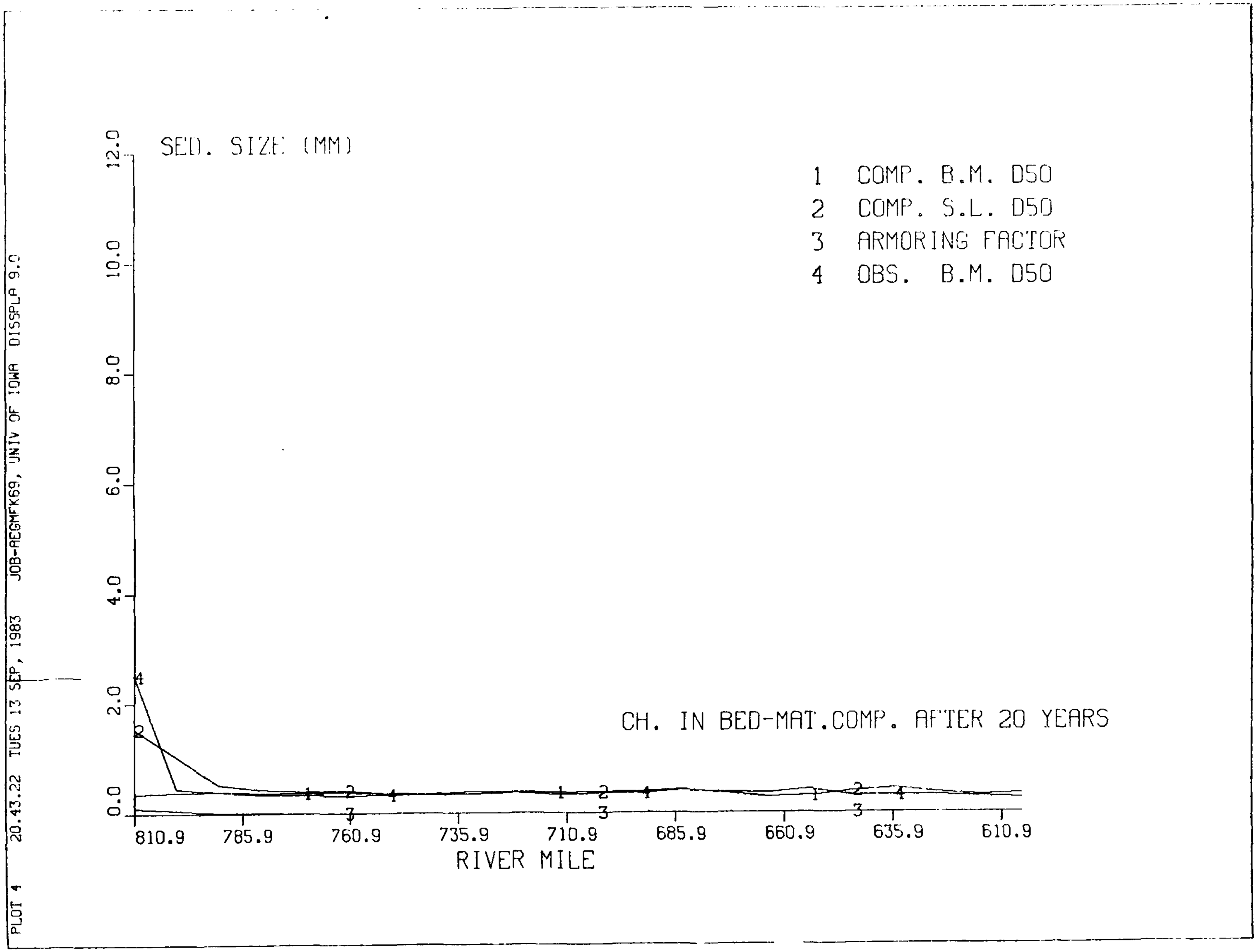


Figure 55. Change in bed-material composition for Run R8 after 20 years

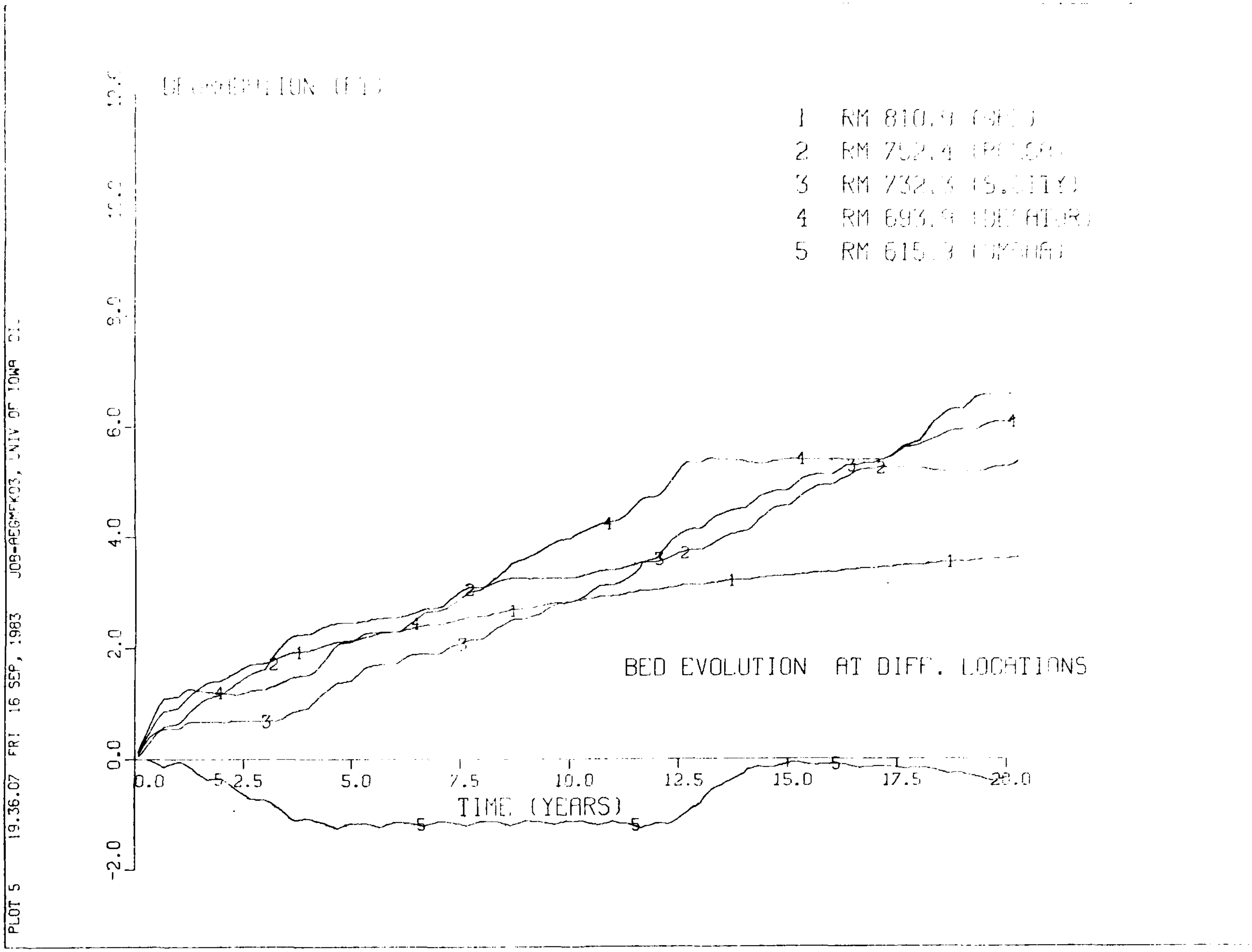


Figure 56. Temporal evolution of bed elevation for Run R1

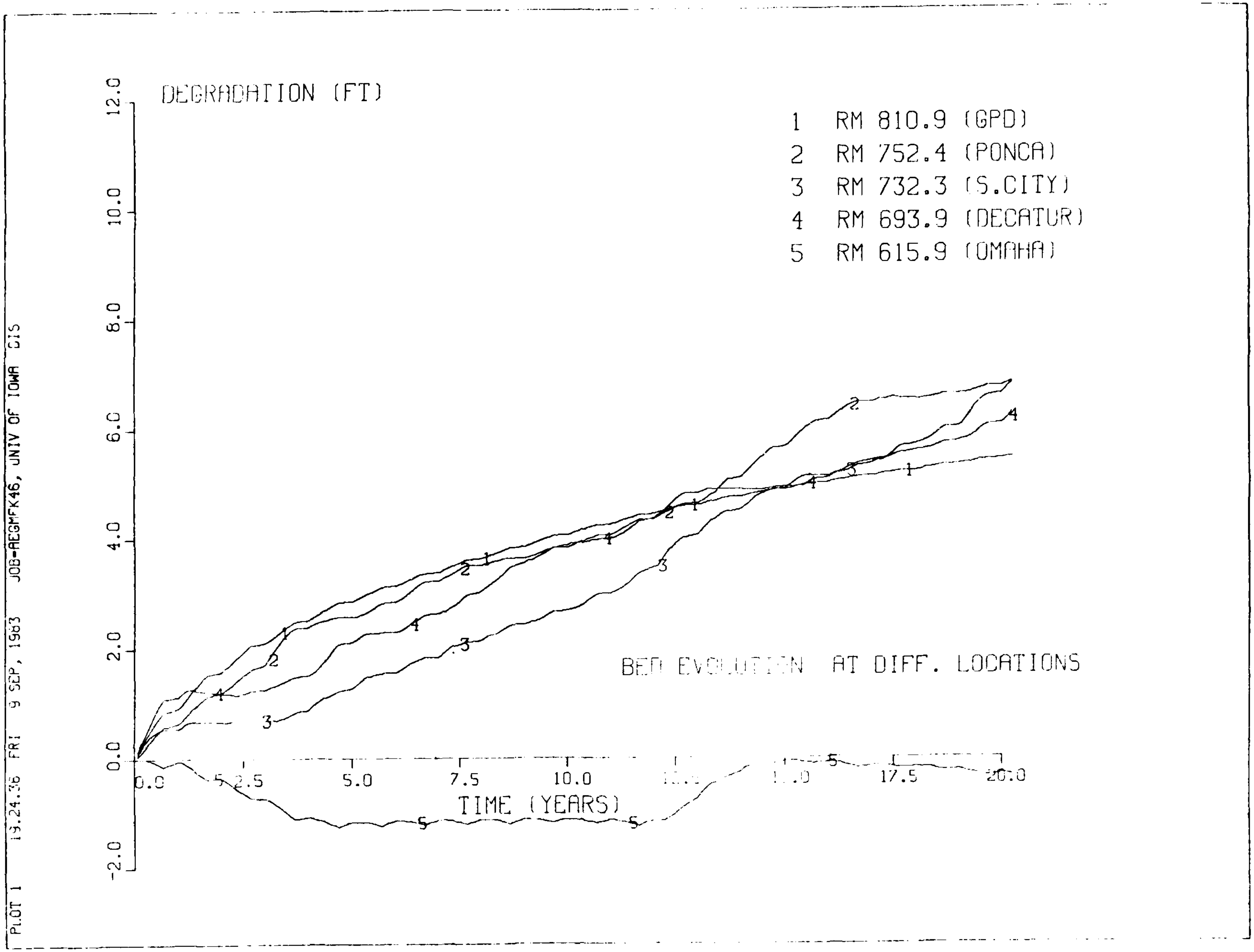


Figure 57. Temporal evolution of bed elevation for Run R2

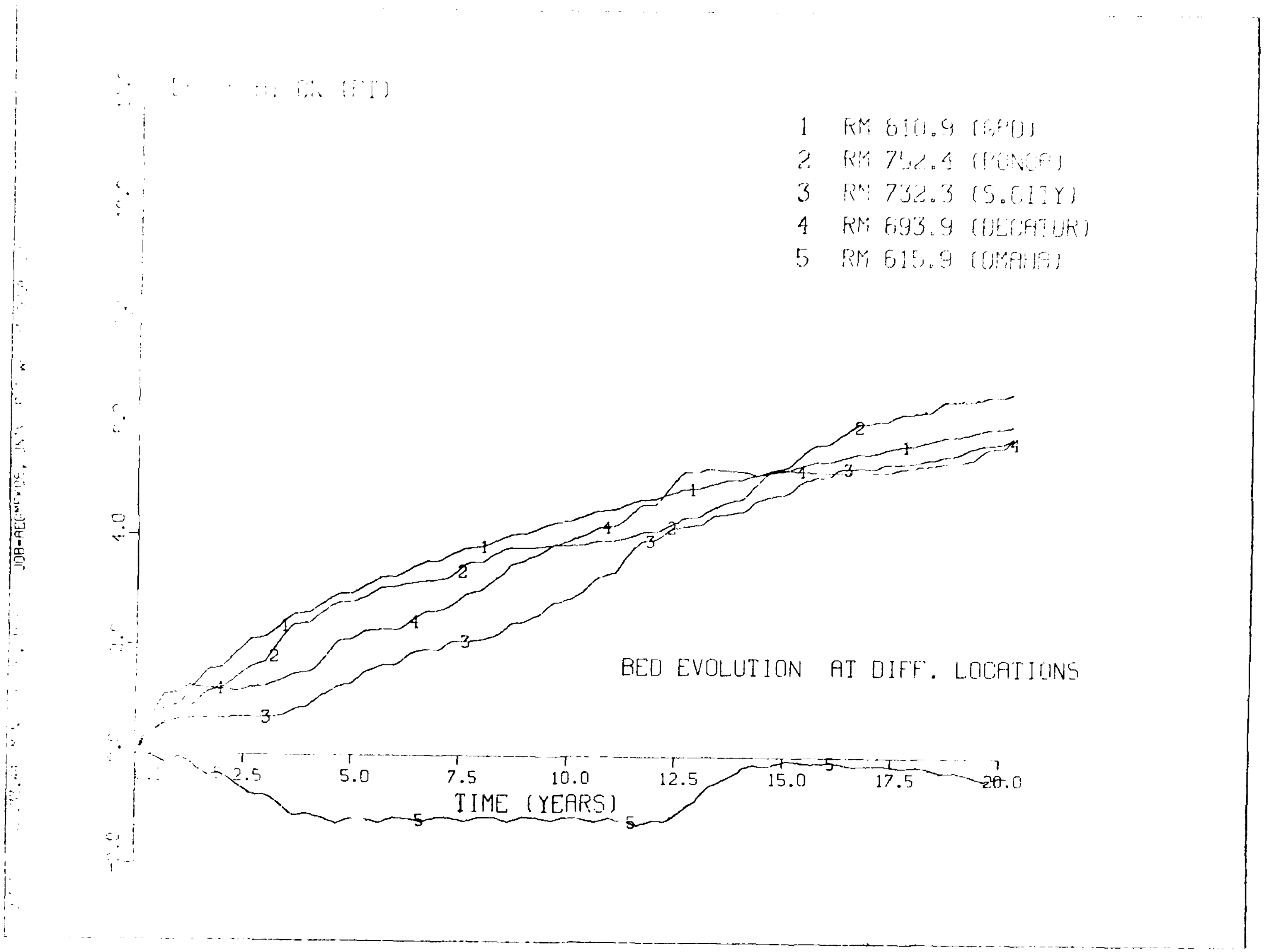


Figure 58. Temporal evolution of bed elevation for Run R3

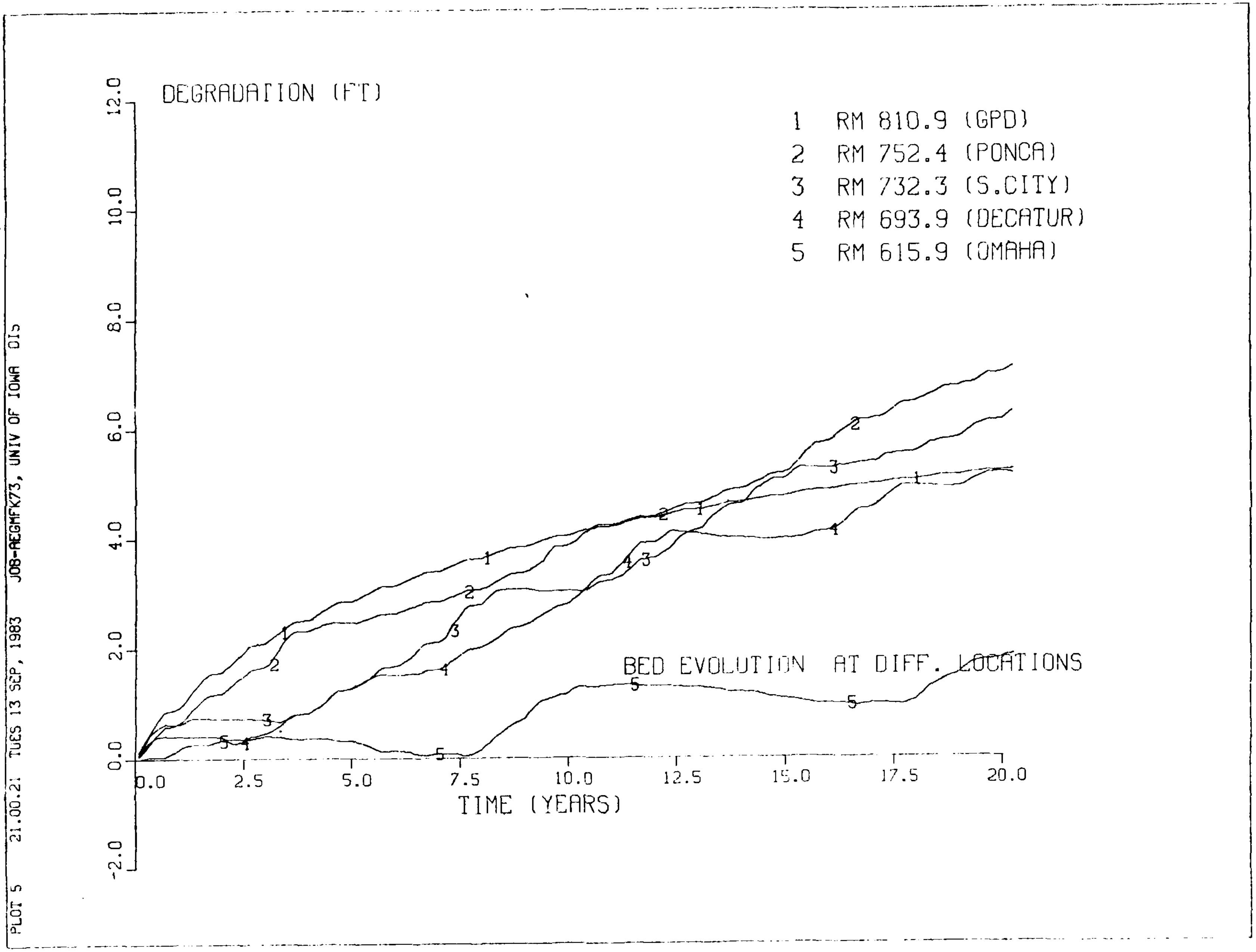


Figure 59. Temporal evolution of bed elevation for Run R4

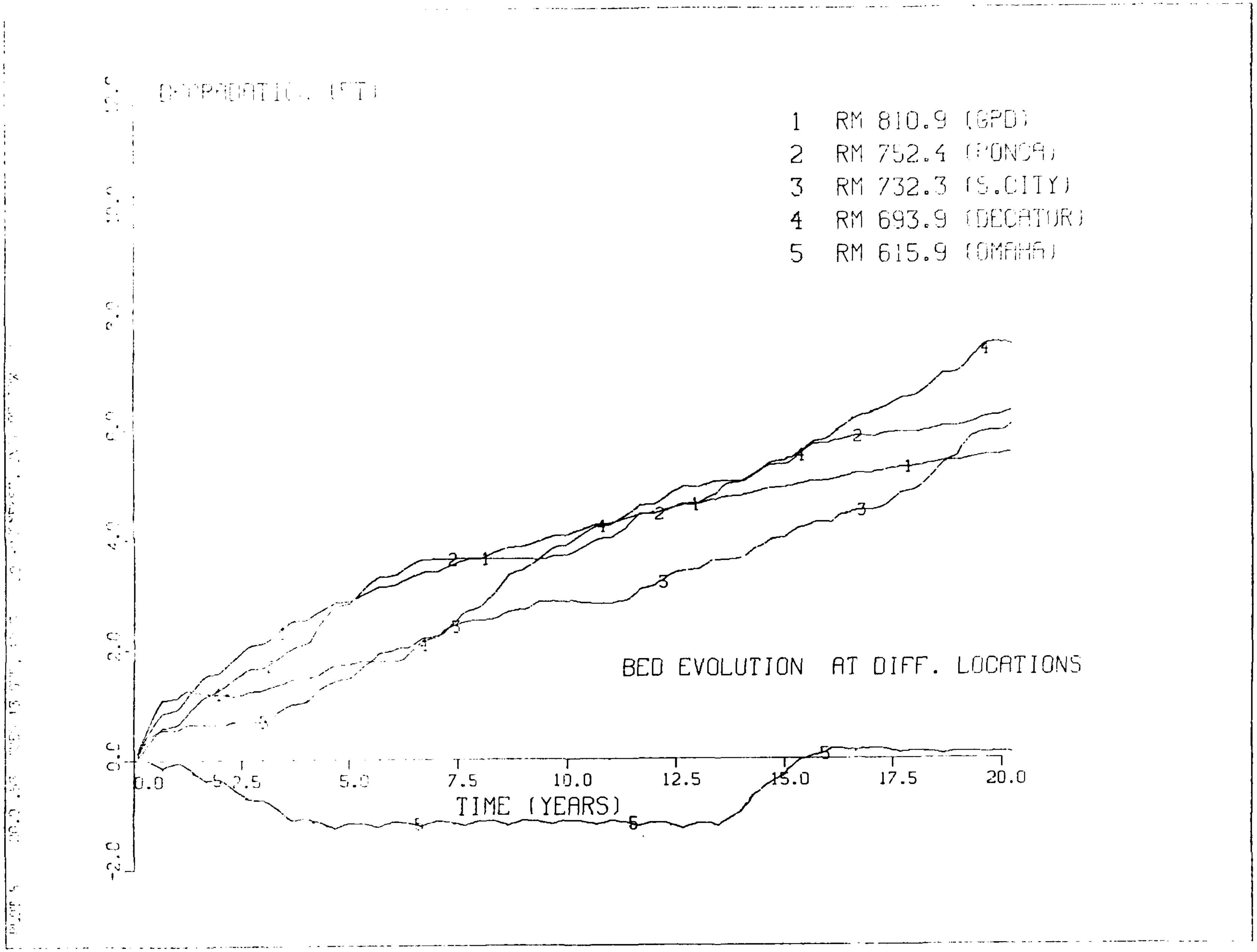


Figure 60. Temporal evolution of bed elevation for Run R5

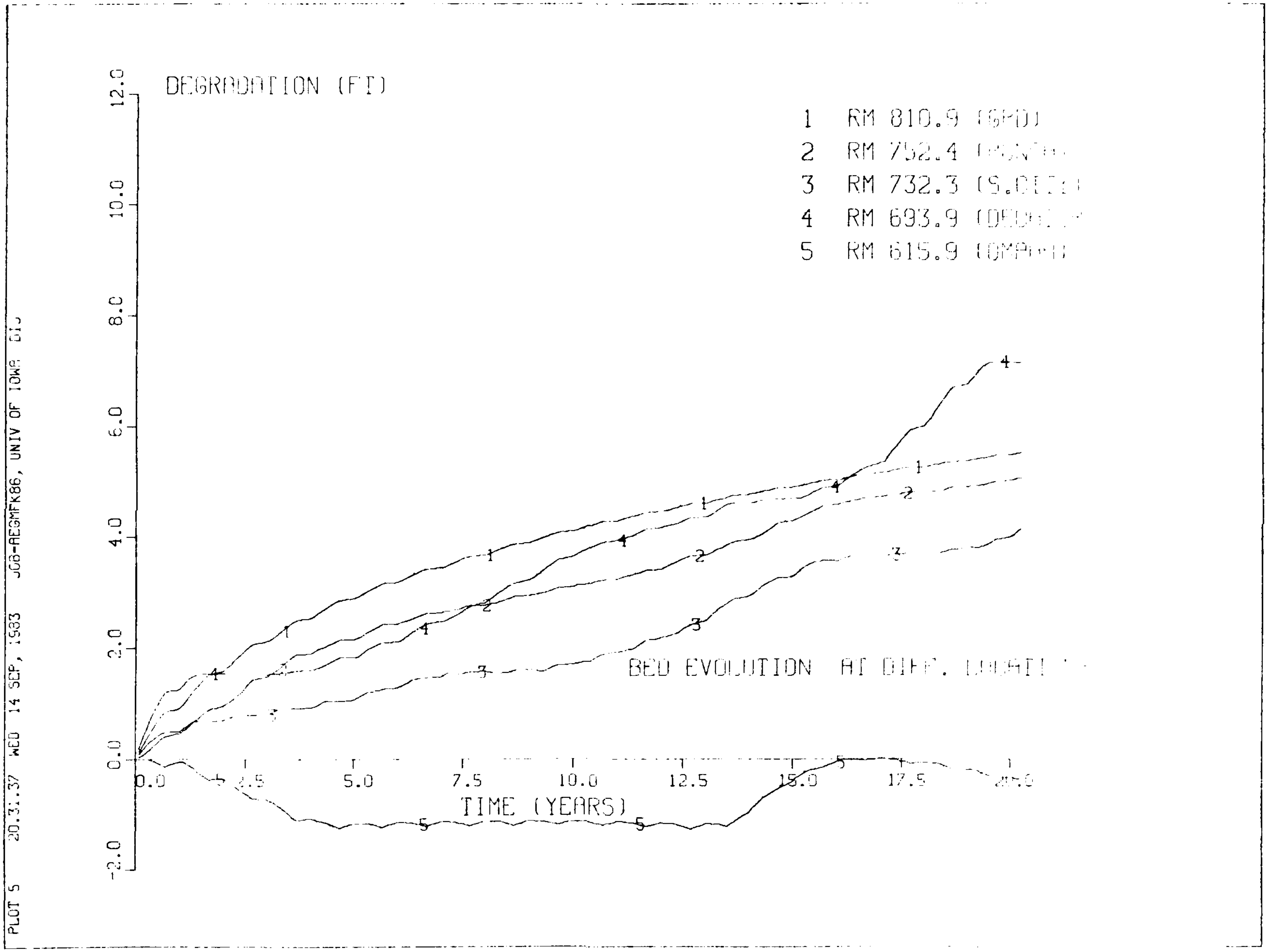


Figure 61. Temporal evolution of bed elevation for Run R6

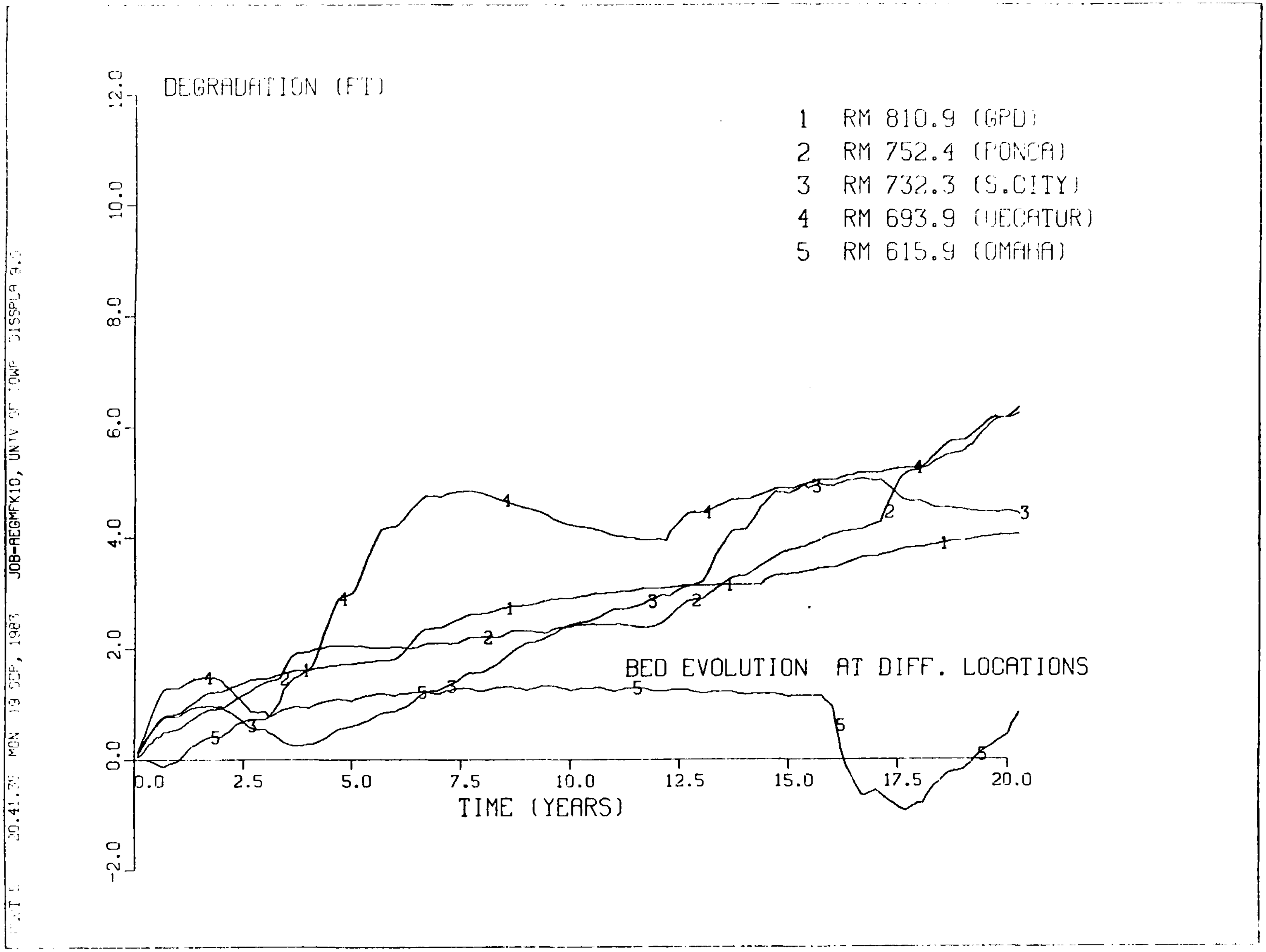


Figure 62. Temporal evolution of bed elevation for Run R7

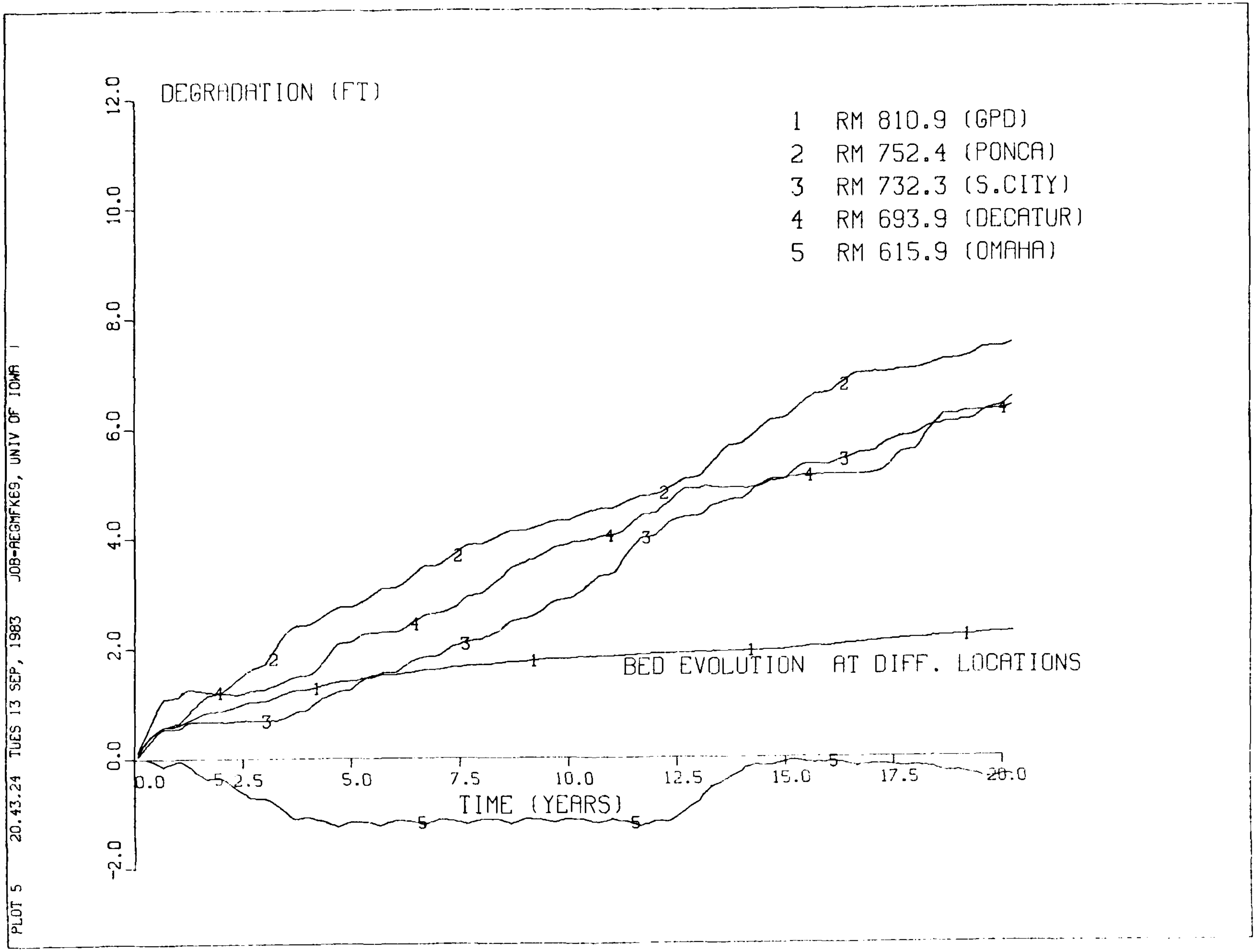


Figure 63. Temporal evolution of bed elevation for Run R8

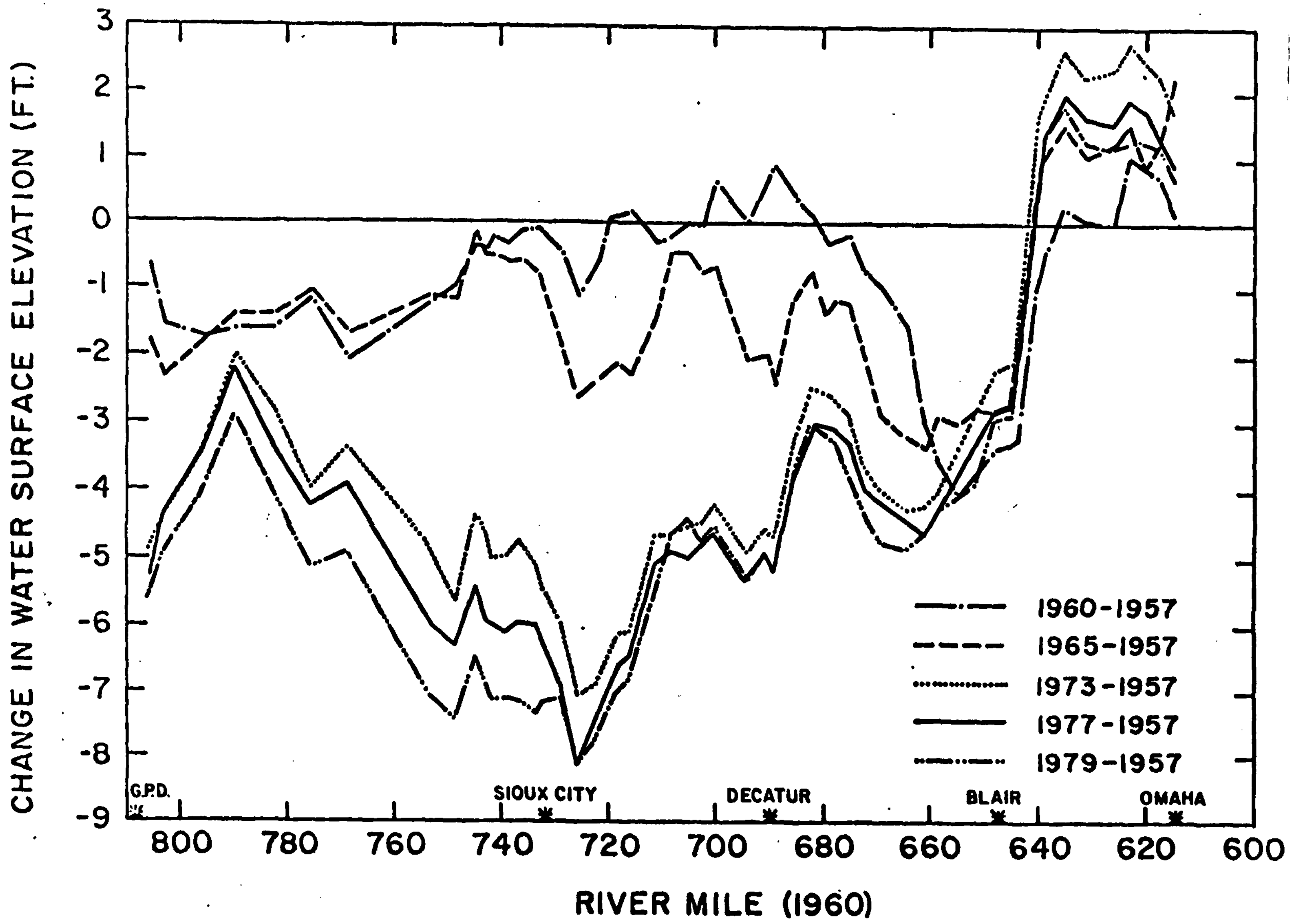


Figure 64. Observed changes in water-surface elevations for Q = 29,500 cfs at Yankton (C.O.E., 1981)

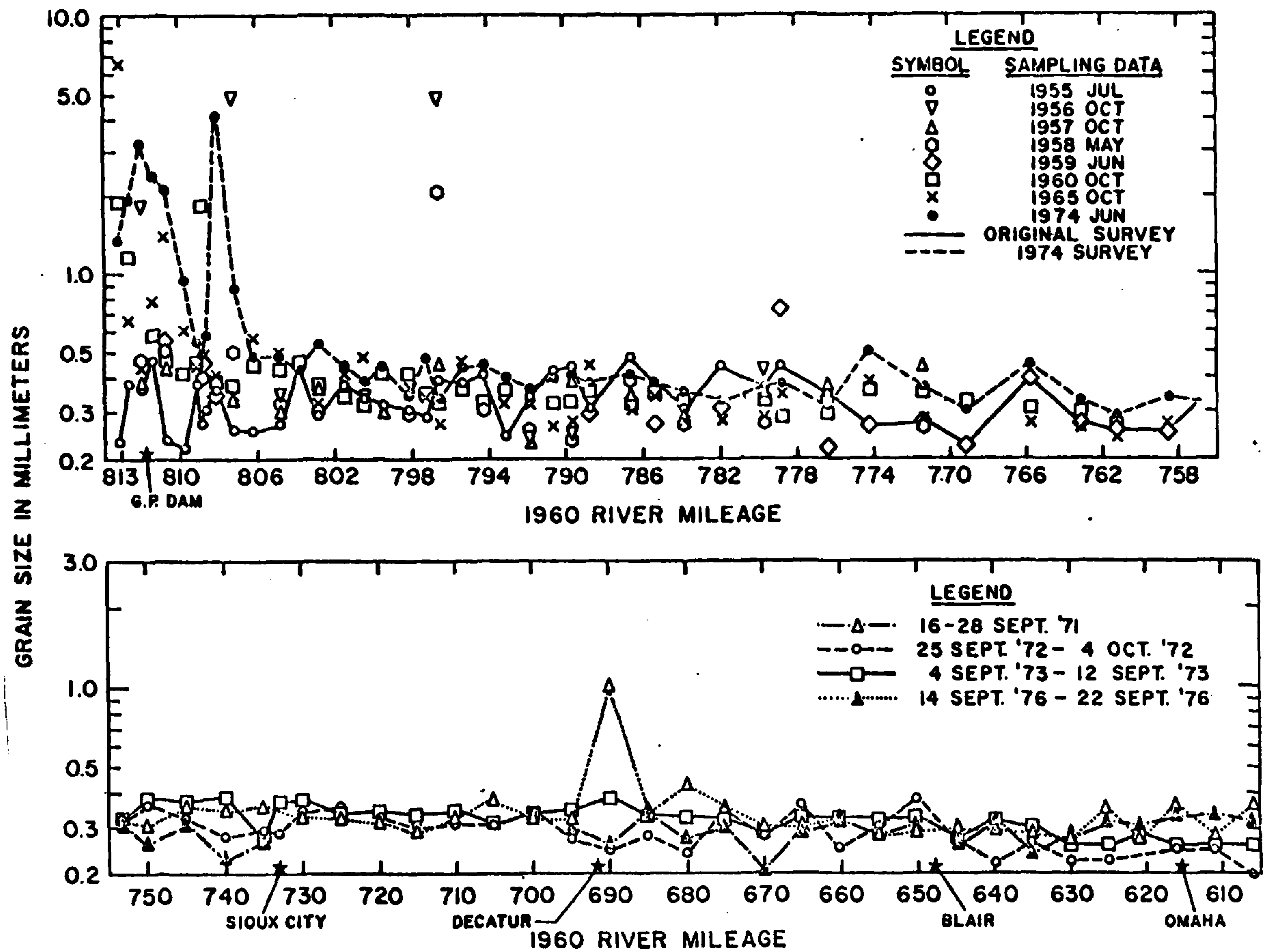


Figure 65. Observed values of median bed-material size (D_{50}) (C.O.E., 1981)

in 1955 to 1.5 - 4.0 mm in 1974, is evident only in the 5-mile subreach downstream from the dam (figure 65). The rest of the reach to Omaha indicates slight coarsening, and even slight decreases in D_{50} at few locations, with the range of D_{50} between 0.25 and 0.50 mm. The results for each of the ten simulation runs described in table 8 are discussed and compared with these observed values in the following sections.

1. Discussion of Run R1. The simulation run R1 corresponds to the old version of IALLUVIAL, before the modifications in armoring and sorting procedures described in Chapter II were incorporated in the present computer code. Computed and observed (where available) changes in bed and water-surface elevations and in bed-material distributions along the study reach at different times are shown in figures 10 through 17. Computed temporal evolution of the river bed at different locations is given in figure 56. Some of the notation appearing in these and other figures is defined below:

DELZ	=	change in bed elevation (ft) (positive for degradation and negative for aggradation);
DELH	=	change in water-surface elevation (ft) (positive for decline and negative for rise);
COMP. CH.	=	computed change
OBS. CH.	=	observed change
COMP. B.M. D50	=	computed bed-material median size (D_{50})
COMP. S.L. D50	=	computed surface-layer mean sediment size = D_{50s} given by Eq. (25)
OBS. B.M. D50	=	observed bed-material median size (D_{50})
ARMORING FACTOR	=	armor-coverage factor (fraction) = $A_f(t)$ given by Eq. (16)

These figures show reasonable agreement between the computed and measured values of changes in water-surface elevations and median bed-material size after 20 years of simulation (1957-77). Further discussion of these results as compared to those of run R2 (present version of IALLUVIAL with the same input data as R1) is given in the next section.

2. Discussion of R2. Run R2 is the basic 20-year (1957-77) simulation of the Missouri River downstream of Gavins Point Dam to Omaha, with the present version of IALLUVIAL; the remaining simulation runs are compared with R2 to investigate the effects of cutoffs, variation in bed-material size distributions, variation in calibration coefficients, and different alternative bed armoring procedures. Figures 18 through 25 and Figure 57 present the various results of simulation for this run. It is seen from figures 18 through 21 that the computed changes in water-surface elevations are in good agreement with the observed values after 16 and 20 years of simulation (figures 20, 21), but agreement is less than satisfactory for simulations after 3 and 8 years (figures 18, 19); the deviations between the computed and observed values (figures 18, 19) are significant particularly near the dam and near the locations of DeSoto Bend (RM 644.2 - RM 641.8) and California (RM 651.0 - 649.3) cutoffs. This slow response of the model in the earlier years may be attributed to the use of idealized cross-sections and bed-material size distributions for the representation of the entire study reach, large discretization grids in space and time (Δx = 9.75 miles and Δt = 30 days), and the approximations in specifying downstream boundary and initial conditions and in representing the cutoffs (cutoffs were represented in input data by increasing initial bed slopes in the affected subreaches). An attempt was made to improve the input data for the latter conditions (i.e., downstream

boundary and initial conditions, and representation of cutoffs), and the results are presented in Section IV.D.10 for run R10. As can be seen from figure 25 and table 9 (see computed changes in bed and water-surface elevations), significant differences between changes in bed and water-surface elevations exist at several locations; this is to be expected because the latter is a function of the former as well as of the friction factor which, in turn, depends on sediment discharge and bed-material composition; comparison of changes in bed and water-surface elevation, therefore, should be viewed in this perspective.

Computed changes in bed-material composition after 3, 8, 16, and 20 years are plotted in figures 22 through 25. These plots show median bed-material size (D_{50}), mean size of the surface layer (D_{50s}, given by Eq. (25)), and the armor-coverage factor (ACF, expressed in fraction of area covered). It is seen from figure 25, which also shows the observed values of D_{50}, that the computed and observed values of D_{50} are in good agreement except near the dam where the observed D_{50} (curve 3) is much coarser than the corresponding computed value (curve 1), and that the armoring factor (ACF) is close to 1.00 near the dam and diminishes rapidly in the downstream direction. The surface-layer mean size, D_{50s}, which is related to the armoring factor (Eq. 25), accordingly increases rapidly with increased armoring in the upstream direction near the dam. The computed bed-material composition after 20 years in the subreach near the dam, thus, consists of two distinct layers: the top layer or the armor coat with mean sediment size of about 10 mm, and the underlying mixed layer with mean size of 0.46 mm; this two-layer composition is depicted in figure 66. Two photographs of the Missouri River bed taken by the third author in March, 1980 (when controlled release from Gavins Point Dam

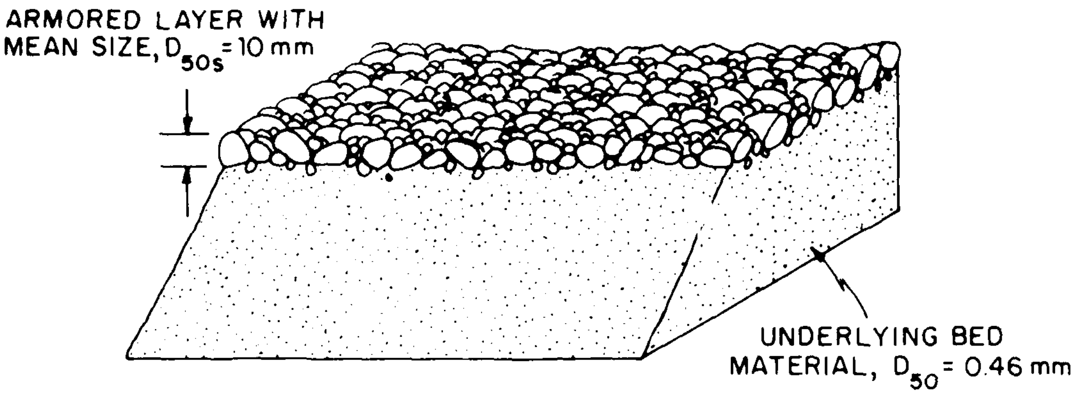
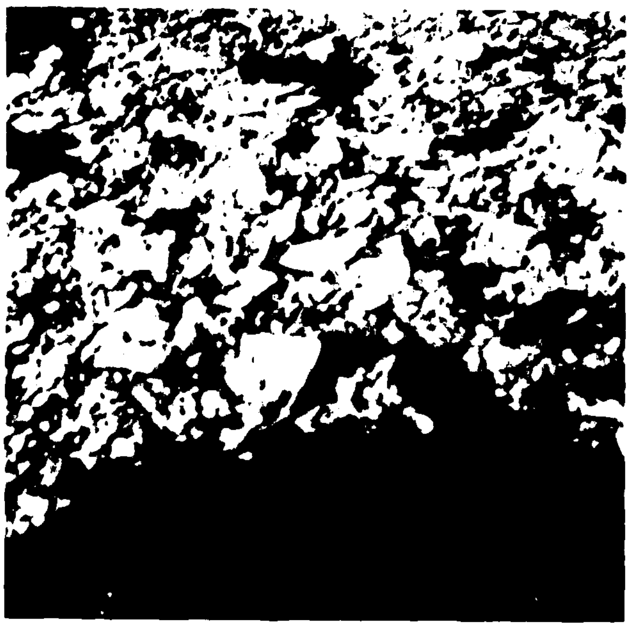


Figure 66. Schematic representation of armored bed near Gavins Point Dam

a. Near RM 810.5, opposite the boat launching pad near Gavins Point Dam



b. Near RM 807.3, about 4 miles downstream of Gavins Point Dam

Figure 67. Photographs of the Missouri River bed armoring (March, 1980)

was interrupted) are given in figure 67. The areal extent of bed armoring is shown in the photographs of figure 68. The similarity in the appearance of the bed composition between figures 66 and 67 is immediately apparent.

The thickness of the top armor layer (figure 67) appears to be roughly one-diameter of the coarsest sediment size, which is consistent with the observation made by Harrison (1950) from his laboratory experiments. It may be argued that the reported observed value of D_{50} as equal to 2.50 mm (figures 25 and 65), as compared to the computed value of 0.46 mm for the underlying mixed layer (figure 25), is a result of the sampling procedure and, more particularly, is a function of the depth of sampling. For example, if the sample was scooped such that it contained equal volumes of the top armored layer and the underlying finer sediments, the median size of the sample would be approximately the average of the mean size of the top layer and the underlying materials. If on the otherhand, the reported D_{50} of 2.50 mm near the dam (figure 25) represents only *the sediments lying below the top armor* layer, this significant coarsening of the bed material, with D_{50} increasing from about 0.40 to 2.50 mm, may be a result of the degrading river bed encountering coarser sediment layers in the alluvium below the bed elevation prevailing at the time of dam closure (1957). In all simulation runs presented herein, it was assumed that the underlying alluvium has the same size distribution as given in tables 3 and 4; this coarsening of the bed materials below the armor coat would not, therefore, be reflected in the present results. It is believed that the simulated bed composition given in figure 25 and illustrated in figure 66 is a reasonable representation of the observed bed composition depicted in figure 67.

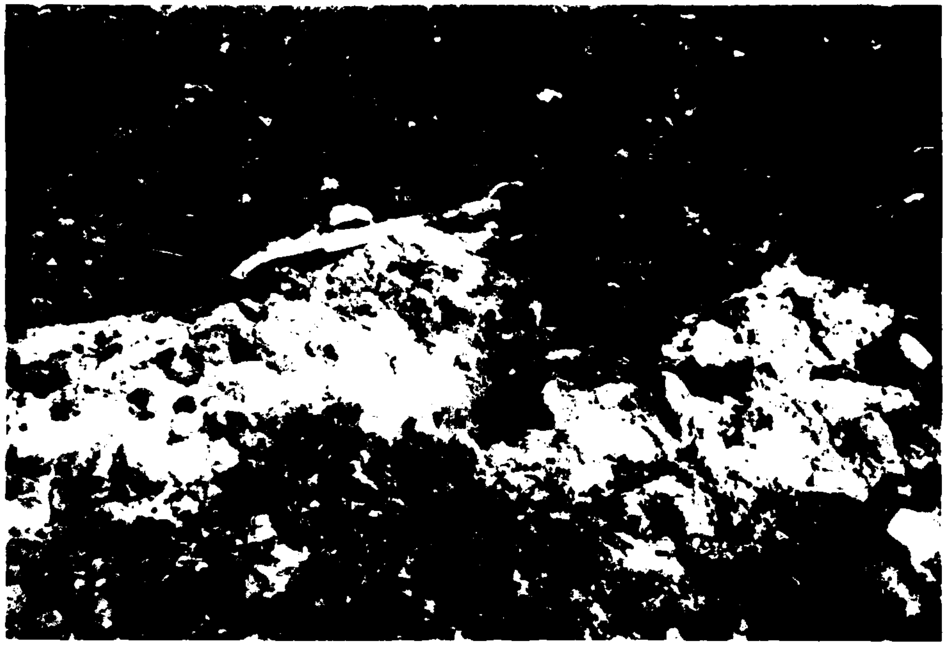
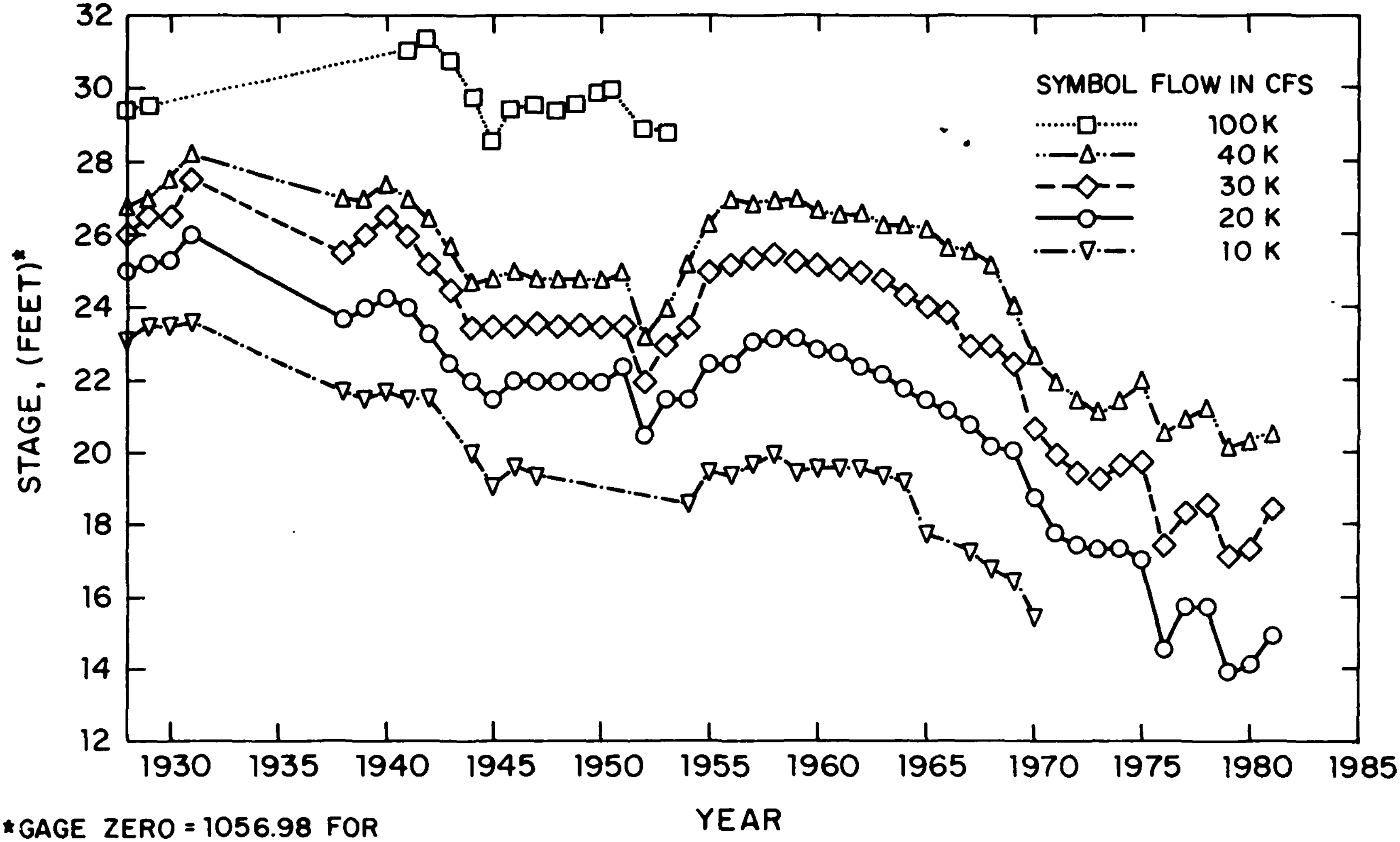


Figure 68. Photographs showing the extent of bed armoring near Gavins Point Dam (March, 1980)

The evolution of the river bed elevation in 20 years since the closure of the dam in 1957 at different locations along the study reach is shown in figure 57. It is seen from this figure that bed degradation, after an initial increased rate, slows down at the end of 20 years at Gavins Point Dam (RM 810.9) and at RM 752.4 (Ponca). The river bed at Omaha (RM 615.9) showed aggradation of about 1.5 feet in the first 5 years, then remained stable for about 7 years, followed by degradation in the next 2.5 years, remaining unchanged since then. This trend in degradation, at these three locations (RM 810.9, 752.4, and 615.9) is in reasonable agreement with observed trends. On the other hand, as indicated in figure 57, the river beds at Sioux City (RM 732.3) and Decatur (RM 693.9) appear to experience degradation at an increased or nearly constant rate at the end of the 20-year simulation. This trend in degradation, particularly at Sioux City, is not in conformity with the observed trend as shown in figure 69; it is seen from this figure that the water surface elevation (for Q = 30,000 cfs), after declining steadily up to 1973, levelled off until 1975, declined 2 feet in 1976, then generally leveled off since then up to 1981. This levelling off in water surface elevation at Sioux City around 1976 (figure 69) is perhaps caused by the degrading bed encountering coarser sediments, or by the presence of increased amounts of the coarsest fractions (which may armor the bed partly) in the parent bed materials. This possibility is investigated in the simulations for runs R5 and R6 and the results are presented in Sections IV.D.5 and IV.D.6.

3. Discussion of Run R3. Simulation run R3 has the same input data as R2, except that the armoring correction coefficients for sediment discharge, friction factor, and mixed-layer thickness -- C_1, C_2, and C_3 given by Eqs. (21), (22), and (23), respectively--are each assigned a value of 0.80



*GAGE ZERO = 1056.98 FOR TOTAL PERIOD SHOWN

Figure 69. Observed stage trends at Sioux City (C.O.E., 1981)

(compared to 1.00 for R2 and other runs). The significance of these coefficients may be interpreted in two ways: first, since the forms of Eqs. (21), (22), and (23) are not known and the assumed linear form is one of many possibilities, the coefficients may be used as calibration parameters; secondly, values of the coefficients less than unity, say 0.80, mean that the armor coat (full or partial) is only 80% effective in preventing the underlying finer materials from being transported by the flow. The results for this run are shown in figures 26 through 30, and 58. A comparison of these figures with those for run R2 shows no significant difference, except near the dam where the bed experienced a greater depth of degradation. Specifically, figures 57 and 58 indicate that both the amount and rate of degradation at RM 810.9 (Gavins Point Dam) are significantly greater for run R3, with no appreciable effect at downstream locations. This result is consistent with the fact that only the subreaches near the dam experienced bed armoring, and so the effect of changing the coefficients will be felt only in these subreaches. A value of 0.80 for C_1 means that the finer sediments in between the larger particles continue to be lifted and transported by the flow and, therefore, degradation will not stop completely (unless slope reduction makes the flow velocity too small to transport any sediment) even when the bed is completely armored, as is shown by curve 1 of figure 58.

4. Discussion of Run R4. This run has the same input data as run R2, except that the initial bed slopes (table 3) are reduced in the subreaches from RM 635.4 to RM 654.9 (DeSoto Bend and California cutoffs, completed in 1960), and from RM 674.4 to RM 684.2 (Middle-Lower Decatur cutoff, completed in 1961), to remove the effects of these cutoffs. The computed changes in bed and water-surface elevations, and bed-material composition in the study reach,

are presented in figures 31 through 35 and 59. A comparison of figures 31 and 21 (for run R2) shows that the introduction of cutoffs caused increased degradation in reaches upstream and increased aggradation (or reduced degradation) in reaches downstream of the cutoffs; in particular, the cutoffs appear to cause a general drop in water-surface elevation of 3 to 4 feet in the reach between approximately RM 640.0 and RM 680.0. The effects of the two cutoffs cannot be separated because of interaction between them; the resultant degradation shown in figure 21 in the reach between them, roughly RM 640.0 to RM 680.0, is the combination of two opposing effects--the tendency of degradation induced by the DeSoto and California cutoffs being counteracted partly by the deposition caused by the Middle-Lower Decatur cutoff.

The downstream and upstream extent of the effects of the cutoffs are clearly demonstrated by comparison of figures 59 and 57 (for run R2); the general aggradation (or little change in bed elevation) at Omaha (RM 615.9) appears to be partly caused by the downstream effect of the DeSoto Bend cutoff. The immediate upstream effect is illustrated by curve 4 in these figures, which indicates that degradation at Decatur (RM 693.9) picked up considerably due to the cutoffs; further upstream, Sioux City (RM 732.3) shows a slight increase in degradation, while the degradation at Ponca (RM 752.4) appears to level off after the accelerated increase in earlier years. The apparent decrease in degradation upstream of Ponca for run R2 (figure 21) compared to run R4 (figure 31 and table 9) is somewhat intriguing; this is, perhaps, the result of dynamic interaction between the degradation wave propagating downstream from the dam and that moving upstream from the cutoffs. In summary, these results show significant effects of the cutoffs on degradation/aggradation pattern in the study reach.

5. Discussion of Run R5. The effect of vertical variation in subsurface bed-material composition on bed evolution is investigated in run R5. The parent bed-material distribution in three subreaches, RM 713.40 to RM 742.65, near Sioux City (RM 732.3) is assumed to contain 3% extra of the coarsest two fractions 4 feet below the initial bed elevation, as given in table 12 (note that D_{50} remains the same); other input data are the same as those of run R2. The results for this run are presented in figures 36 through 40, and 60. It is seen from table 11 and figure 40 that the river bed near Sioux City becomes slightly armored (about 6%), which reduces degradation in these subreaches (compared to run R2) by about 0.7 feet maximum; this reduction is, however, accompanied by an increase in degradation of comparable magnitude for about 50 miles downstream. The same trend is shown in figure 60, which indicates a reduction in degradation at Sioux City and Ponca (RM 752.4), but an increase at Decatur (RM 693.9); effects on bed elevations at the Gavins Point Dam and Omaha (RM 615.9) are negligible.

Thus an increase in armoring fractions by only 3% does have a significant, but not dramatic, effect on the degradation pattern. The river bed at Sioux City is in an active state with continuous formation and propagation of dunes, with sufficient velocity to transport the coarser fractions (listed in table 12), or to prevent their accumulation on the bed surface because of the mixing process associated with moving bed forms (as discussed in Chapter II). For example, the same increase in armoring fractions in subreaches near the dam (less active bed with lower velocity) would lead to a more pronounced increase in bed armoring and consequent reduction in degradation. The effect of coarser bed material (larger D_{50}) is discussed in the next section.

6. Discussion of Run R6. This run has the same input data as run R2, except that a part of the study reach, RM 684.15 to RM 742.65, has coarser bed material with D_{50} = 0.385 mm (size distribution given in table 12) as compared to D_{50} = 0.297 mm in the rest of the study reach. The results of the simulation with this input data are shown in figures 41 through 45, and 61. A comparison of the computed changes in bed and water-surface elevations after 20 years, shown in figure 41, with the corresponding plot for run R2, figure 21, clearly indicates a decrease in degradation by as much as 2.6 ft in the subreaches with coarser bed sediments, and an increase in degradation of comparable magnitude in a few downstream subreaches. This same trend is shown by figure 61, in which both the rate and magnitude of degradation are decreased at Ponca (RM 752.4, curve 2) and Sioux City (RM 732.3, curve 3), and increased at Decatur (RM 693.9, curve 4), as compared with the corresponding plot for run R2, figure 57. The computed bed-material D_{50}'s after 20 years, as seen from figure 45, are slightly larger than the observed values for the subreaches in which coarser bed sediments were used as input. Thus, these results show significant effect of variation in initial bed-material composition on the pattern of degradation/aggradation in the study reach.

7. Discussion of Run R7. The preceeding six simulation runs used the bed armoring procedures described in Sections II.C.1 through II.C.4. Simulation R7 replaces this armoring scheme with the bed-layer procedure, in which a bed layer is assumed to form at the top of the mixed layer, as described in Section II.C.5. The assumption in this procedure is that the bed layer, being much thinner than the mixed layer, would coarsen faster and therefore would indirectly take into account the effect of bed armoring by using the bed-layer sediment size in sediment discharge and friction factor

Table 12

Bed-Material Composition for Run R5 and Run R6

For Run 5: Vertical Variation in Bed-Material Distribution near Sioux City

Subreach	Depth below initial bed	Fraction of sediment size (mm) interval .062-.149	.149-.297	.297-.590	.590-1.190	1.190-2.400	2.400-4.800	4.800-9.520	9.520-19.100	D_{50} (mm)
RM 713.4 to RM 723.15	Upto 4 feet below bed	0.105	0.395	0.350	0.085	0.035	0.030	0.0	0.0	0.297
	More than 4 feet below bed	0.105	0.395	0.350	0.085	0.025	0.010	0.005	0.025	0.297
RM 723.15 to RM 732.90	Upto 4 feet below bed	0.105	0.395	0.350	0.085	0.035	0.030	0.0	0.0	0.297
	More than 4 feet below bed	0.105	0.395	0.350	0.085	0.025	0.010	0.005	0.025	0.297
RM 732.90 to RM 742.65	Upto 4 feet below bed	0.105	0.395	0.350	0.085	0.035	0.027	0.003	0.0	0.297
	More than 4 feet below bed	0.105	0.395	0.350	0.085	0.025	0.007	0.008	0.025	0.297

For Run R6: Bed-Material Distribution in RM 684.15 to RM 742.65

Subreach	Depth below initial bed	.062-.149	.149-.297	.297-.590	.590-1.190	1.190-2.400	2.400-4.800	4.800-9.520	9.520-19.100	D_{50} (mm)
Rm 684.15 to RM 742.65	Infinite depth below bed	0.105	0.245	0.500	0.085	0.035	0.030	0.0	0.0	0.385

calculations. The same input data as in run R2 are used in this run. Figures 46 through 50, and 62 present the results of this simulation. It is seen from figures 47 through 50 that the computed bed-layer D_{50} (curve 1) becomes alternately very coarse (more than 1 mm) and fine along the whole reach; this oscillation was found to be larger in early years with gradual attenuation with time. This wide variation in D_{50} along the reach is not in conformity with the observed trend (figure 65), in which D_{50} varies within a very narrow range of 0.3 to 0.45 mm (except in the subreach near the dam).

This wide variation in D_{50} is reflected in the results for computed changes in bed and water-surface elevations given in figure 46, because of the interdependence between sediment discharge and friction factor used in the formulation of IALLUVIAL. In particular, the computed and observed changes in water-surface elevations after 20 years, plotted in figure 46, show rather poor agreement; this is a direct result of poor agreement between the computed and observed D_{50}'s. The reason for the apparent oscillation in D_{50} values along the reach is, perhaps, the over-sensitivity of the size distribution of bed-layer materials, often containing very small amounts of certain size fractions, to even small amounts of scour/deposition in a particular time period. These results show that this procedure requires further refinement before realistic predictions of bed-material composition and evolution of bed and water-surface elevations can be made.

8. Discussion of Run R8. This run uses the surface-layer procedure described in Section II.C.6. Normal armoring procedures are used to compute the armor-coverage factor, which, in turn, is used to compute the surface-layer mean sediment size, D_{50s}, by Eq. (25); however no correction for armoring is made on sediment discharge, friction factor, and mixed-layer

thickness (i.e., $C_1 = C_2 = C_3 = 0$ in Eqs. (21), (22), and (23)). D_{50s}, instead of D_{50} of the mixed layer, is used in all sediment discharge and friction factor calculations. The dependence of D_{50s} on armoring, through Eq. (25), is assumed to account for the effect of armoring on sediment discharge and friction factor. Figures 51 through 55, and 63 present the results for run R8. It is seen from figures 52 through 55 that D_{50s} (curve 2) near the dam rises rapidly with time, slowing down both degradation and armoring near the dam; after 20 years, degradation at the dam is only 2.25 feet and the armor-coverage factor is 11%, compared to the corresponding values of 5.45 feet and 100% for run R2 (tables 9, 11; figures 21, 51). This significant reduction in degradation and armoring near the dam appears to induce some changes in downstream reaches, as can be seen from comparison of figures 63 and 57 (for run R2); compared to run R2, degradation at Ponca (RM 752.4) is slightly increased, with some reduction at Sioux City (RM 732.3) and Decatur (RM 693.9).

The agreement between computed and observed water-surface elevation changes in subreaches near the dam is not satisfactory (figure 51); the computed armor-coverage factor of 11% at the dam (table 11) is too low, compared to the observed value (figure 67). In view of this, the surface-layer procedure does not appear to offer any advantage over the basic armoring procedure described in Sections II.C.1 through II.C.4 and used in the simulation for run R2.

9. Discussion of Run R9. In all preceeding simulation runs, the downstream boundary was 9.75 miles (one subreach length) downstream from Omaha (RM 615.9). In run R9, the downstream boundary is moved downstream (using the same bed slope as at Omaha) by four subreaches, or 48.75 miles downstream from

Omaha, to investigate the effects of the downstream boundary condition on the pattern of degradation/aggradation in the study reach from Gavins Point Dam to Omaha. All other input data are the same as for run R2. The water surface elevation, computed from uniform-flow depth for the initial bed slope for each water discharge, is fixed at the most downstream computational section. Figures 70 through 75 summarize the results for this run. It is seen from figures 70 and 75, as compared to the corresponding figures 21 and 57 for run R2, that slight (but non-negligible) differences exist in the downstream half of the study reach; for example, degradation at Sioux City (RM 732.3) is reduced by about one foot after 20 years, accompanied by an increase of about the same amount at Decatur (RM 693.9). Differences in the overall pattern of degradation (figures 21 and 70), however, are not significant.

10. Discussion of Run R10. Run R10 is a 3-year simulation (1957-60), with the same input data as Run R2. As discussed in Section IV.D.2, run R2 was not able to give a satisfactory simulation of the effects of three bend cutoffs - DeSoto Bend, California, and Middle-Lower Decatur cutoffs--in the early years, even though the 20-year prediction was in reasonable agreement with the observed trend. The purpose of this run is to improve the initial and boundary conditions and attempt to simulate the effects of these cutoffs in the first 3 years. For this purpose, the downstream boundary was moved 48.75 miles downstream from Omaha (RM 615.9) to reduce the effects of the boundary condition. The program was first run without the presence of cutoffs, by increasing the lengths of the affected subreaches by the amount of shortening of the subreaches due to cutoffs. The initial bed and water-surface elevations along the study reach obtained from this run were recorded. The program was then rerun with the lengths of the affected

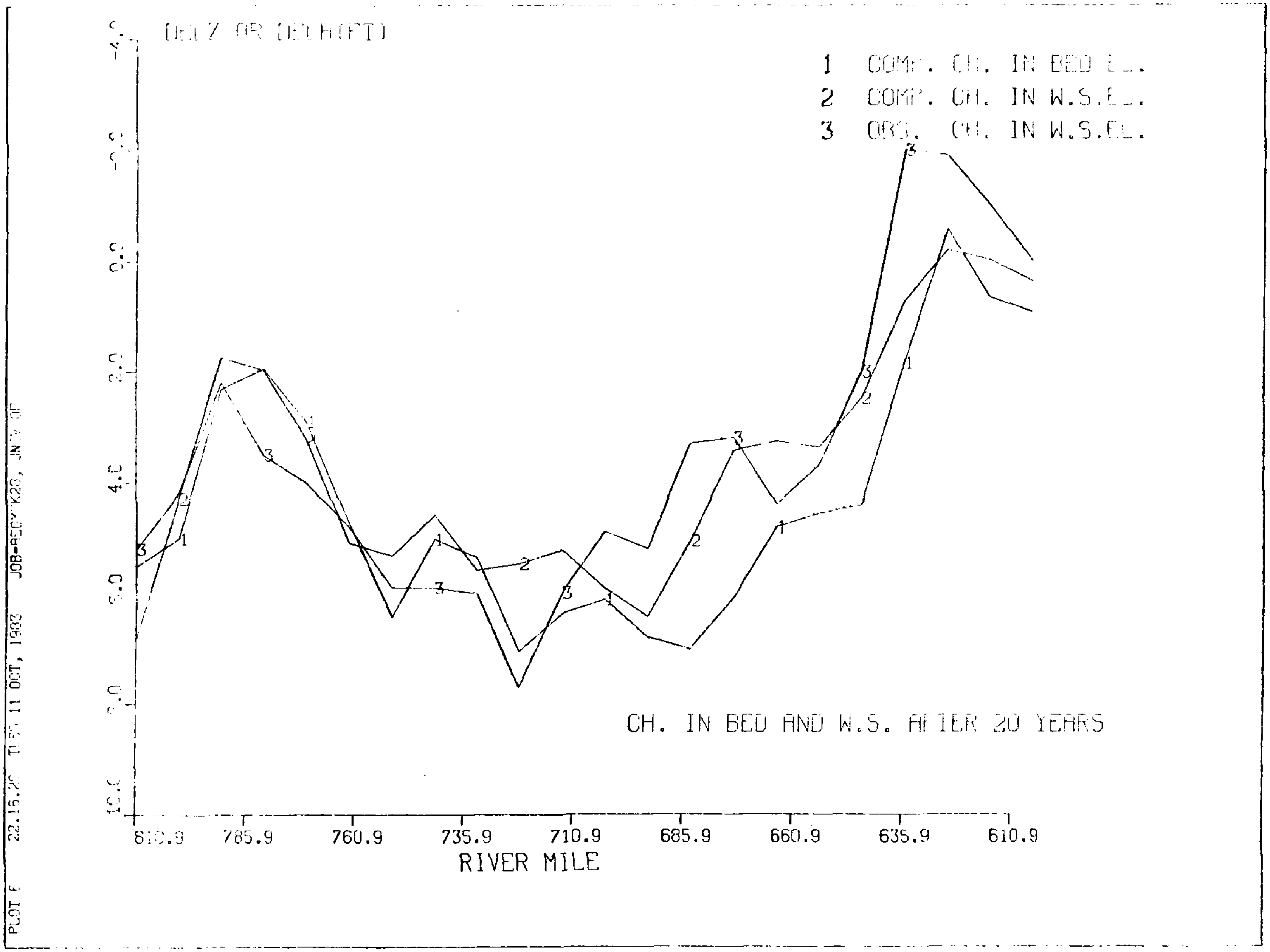


Figure 70. Change in bed and water-surface elevations for Run R9 after 20 ye

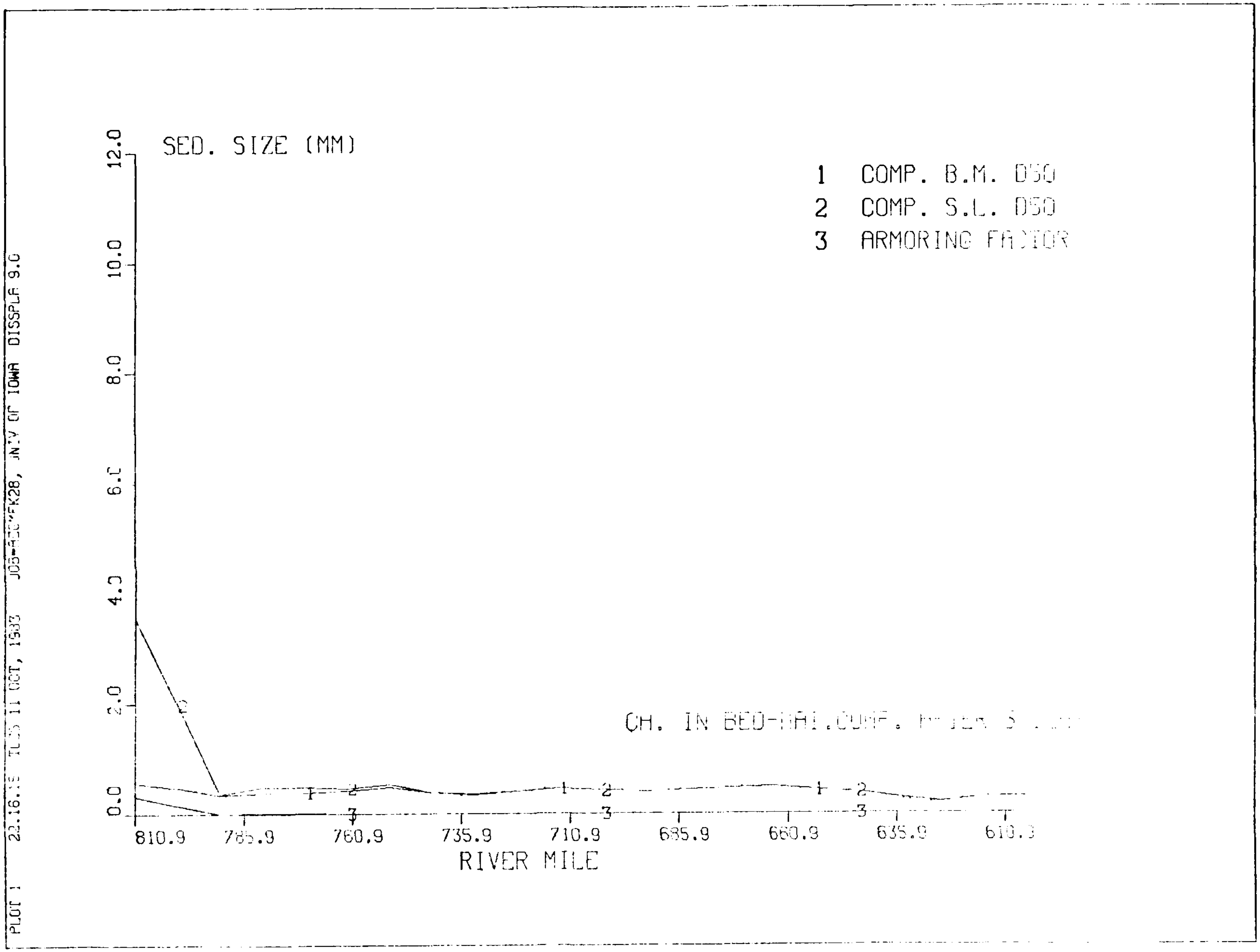


Figure 71. Change in bed-material composition for Run R9 after 3 years

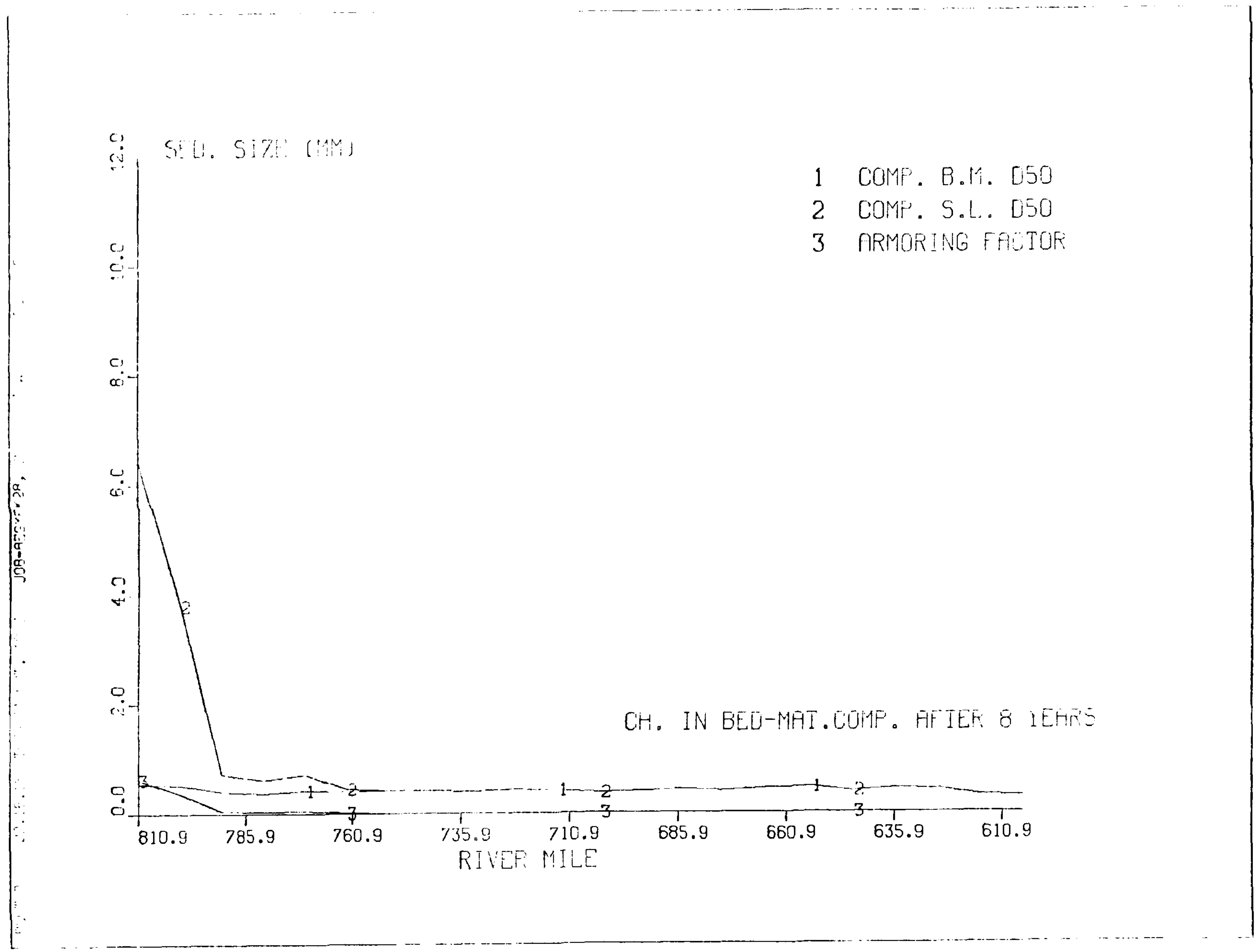


Figure 72. Change in bed-material composition for Run R9 after 8 years

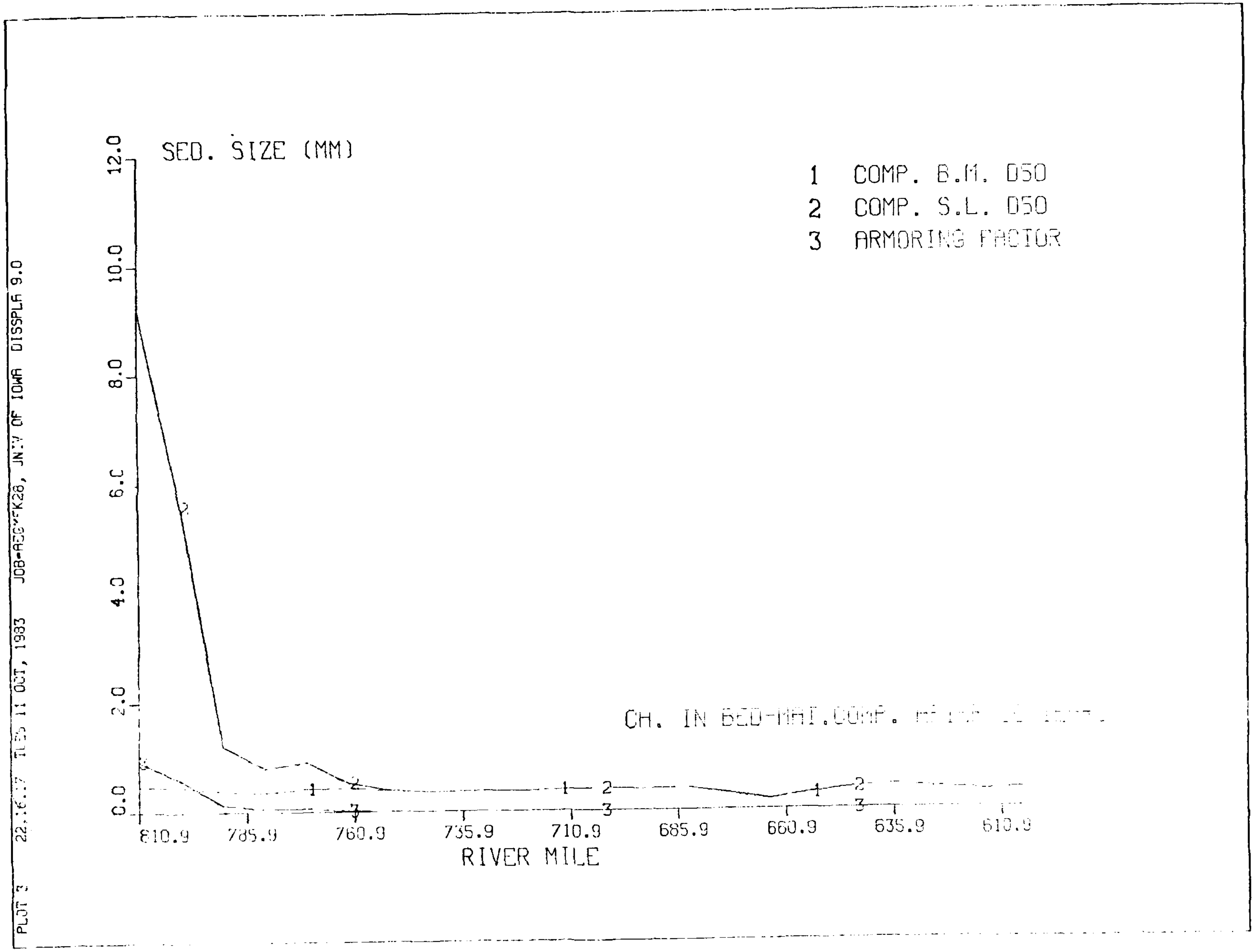


Figure 73. Change in bed-material composition for Run R9 after 16 years

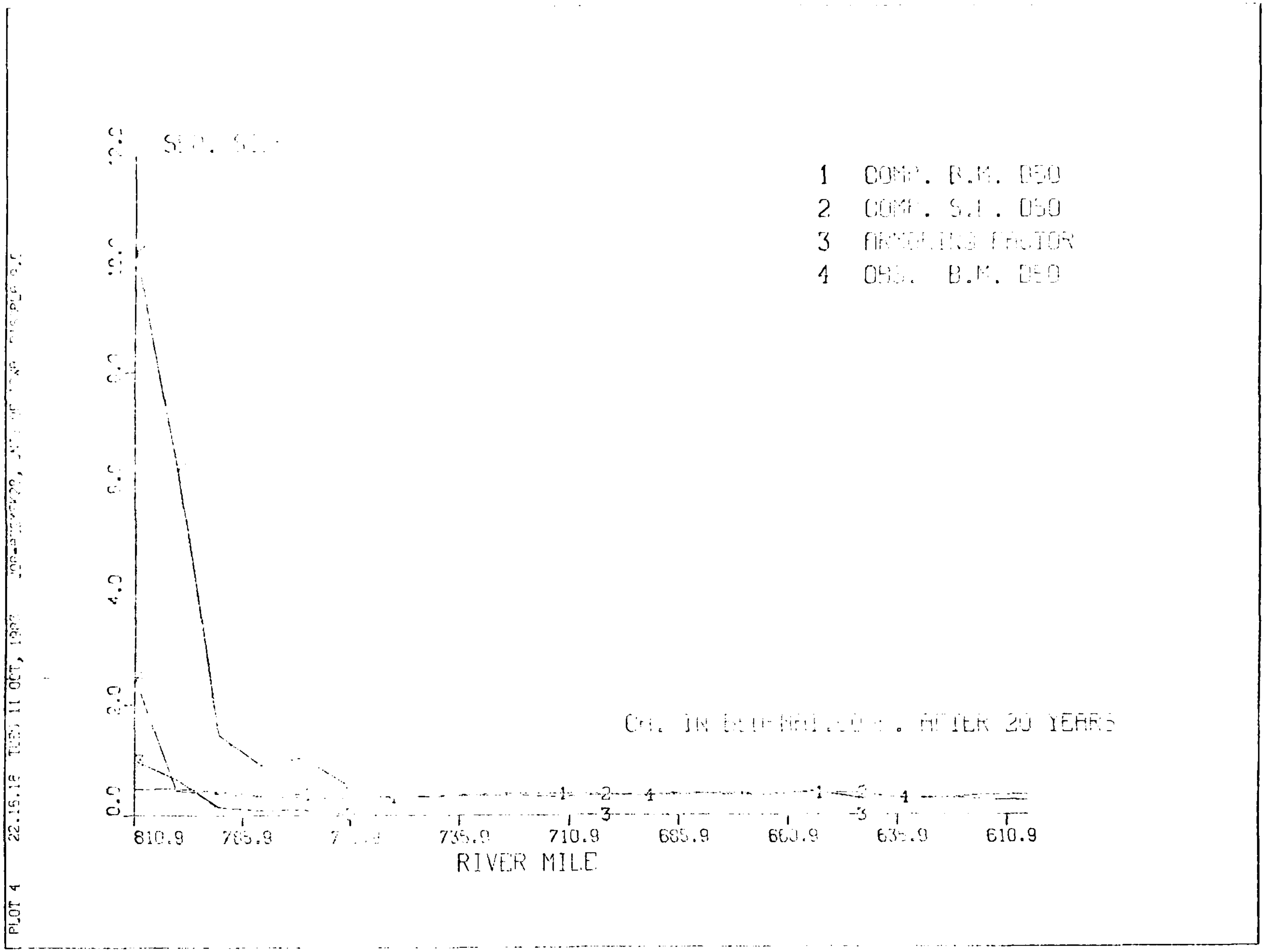


Figure 74. Change in bed-material composition for Run R9 after 20 years

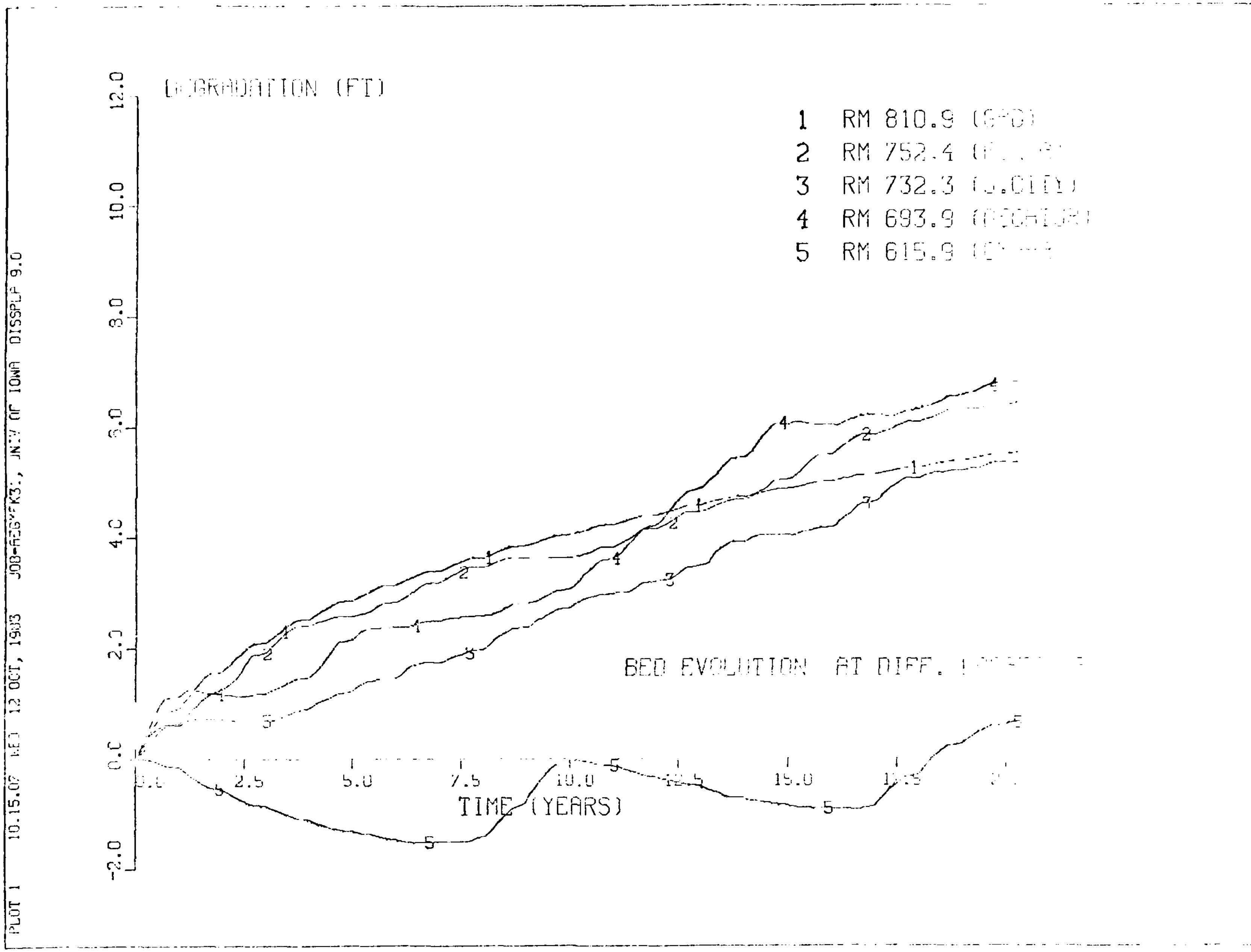


Figure 75. Temporal evolution of bed elevation for Run R9

subreaches shortened to incorporate the effects of cutoffs. The computed bed and water-surface elevations after 3 years of simulation with this run were subtracted from the corresponding values of the first run to obtain the changes in bed and water-surface elevations due to presence of the cutoffs; these values are plotted in figure 76, along with the observed changes in water-surface elevations after 3 years (1957-60). Figure 76 gives a better prediction, as compared to that for run R2 (figure 18), of the observed drops in water surface elevations near the locations of the three cutoffs; the prediction of observed decreases in water-surface elevations in subreaches near the dam, however, is not satisfactory. The latter discrepancy is probably due to the idealized rectangular cross-sections used in the model. The reach from Gavins Point Dam to Ponca (RM 752.4) has a high variability in cross-sectional shapes and sizes; this reach is also subjected to considerable bank erosion which has increased the channel width by as much as 30% at some locations (Williams and Wolman, 1981). Furthermore, the subreach length of Δx = 9.75 miles used in the present simulations is too large to account for such variability in cross-sectional and sediment characteristics of the reach. In view of these limitations, the inadequacy in the prediction of water-surface profiles after 3 years, shown in figure 76, is not entirely unexpected. It is, however, interesting to note that the effects of these approximations in the initial geometric and sediment characteristics are reduced with increasing time of simulation, as can be expected, and is evidenced by reasonable agreement in computed and observed water surface profiles after 15 and 20 years of simulation, in figures 20 and 21, respectively.

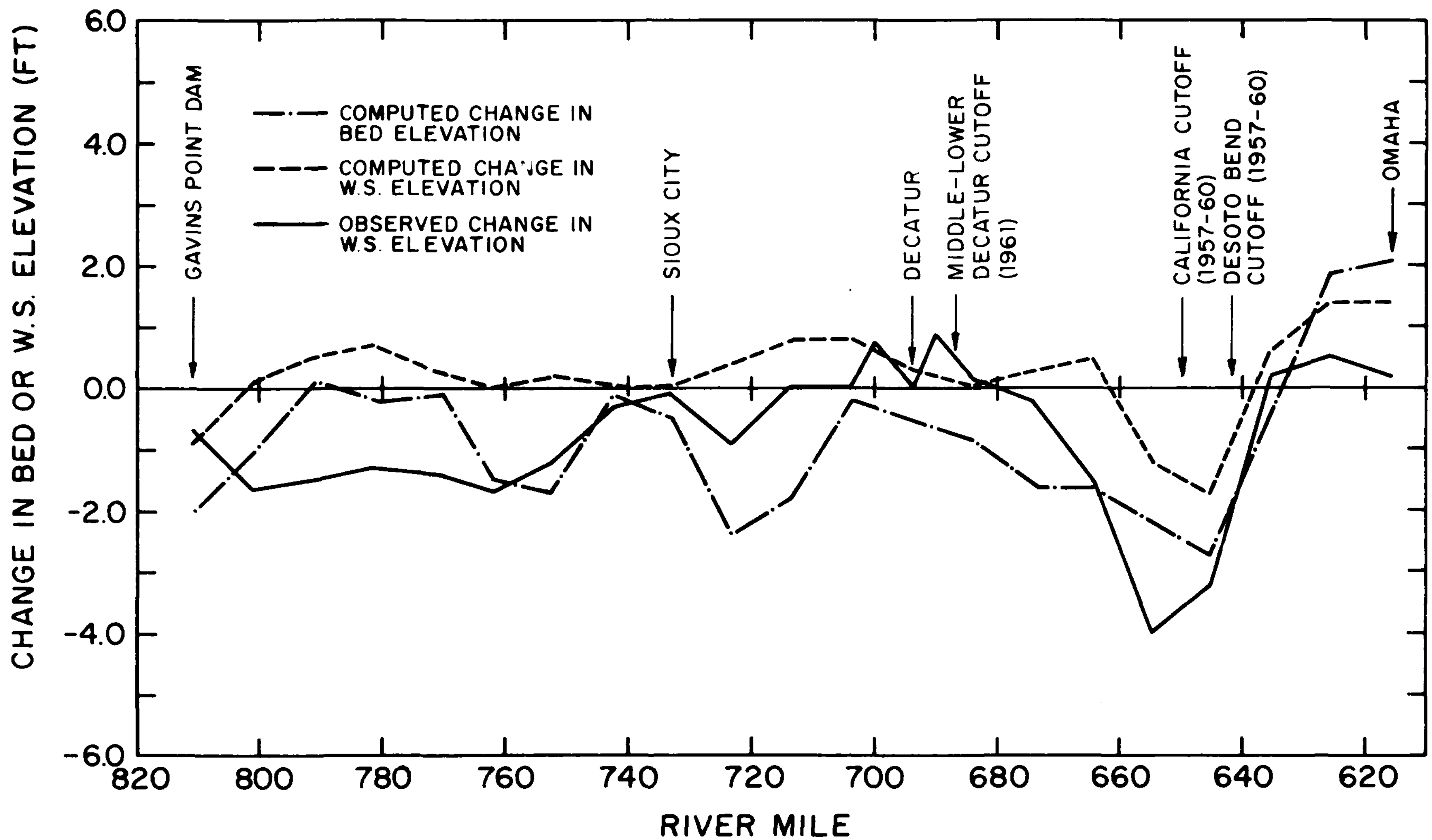


Figure 76. Computed and observed changes in bed and w.s. elevations after 3 years (1957-60) for Run R10

11. Summary of Discussions. The results from ten different simulation runs on the Missouri River reach between Gavins Point Dam and Omaha are presented and discussed in the preceding sections of this chapter. The purpose of these simulations was to evaluate the effectiveness of the present version of IALLUVIAL in predicting the 20-year changes in bed and water-surface elevations and bed-material composition since the closure of the Gavins Point Dam in 1957, and to study the sensitivity of degradation/aggradation patterns in the reach on channel cutoffs, changes in bed-material size distributions, downstream boundary conditions, and variations in some empirical coefficients appearing in the formulation of the model.

The present code of IALLUVIAL incorporates extensive modification of the bed armoring procedure, which has been found, as shown by the results of run R2 in figures 66 and 67, to yield satisfactory prediction of bed armoring of the Missouri River downstream of Gavins Point Dam. The computed changes in water-surface elevation and bed-material sizes in run R2 are found to be in reasonable agreement with the observed values (figures 21, 25). Two alternative schemes--bed-layer and surface-layer procedures for simulation of bed armoring were investigated with results given by the simulations R7 and R8, and found to be unsatisfactory. It was concluded that the armoring procedure described in Sections II.C.1 through II.C.4 and used in run R2 is satisfactory for simulating the Missouri River reach under study.

In the remaining simulation runs, runs R3 through R10, the same input data as for run R2 are used, except that some selected input data and parameters were changed in order to study their effects in comparison with the basic simulation R2. In run R3, the coefficients C_1, C_2, C_3 of Eqs. (21), (22), and (23) (which incorporate the effects of armoring on sediment

discharge, friction factor and mixed-layer thickness) were each changed from their usual values of unity to 0.80; this resulted in a slight increase in degradation near the dam, without any significant effect in the rest of the reach. Three important channel cutoffs (DeSoto, California, and Middle-Lower Decatur cutoffs, completed during 1957-61) were removed in run R4, so that their effects could be investigated by comparison with run R2 which includes these cutoffs. It was found that these cutoffs exerted considerable influence on degradation/aggradation pattern in the study reach; the sharp drop in water-surface elevations in the affected subreaches (which were shortened) were accompanied by significant amounts of degradation and aggradation in the neighboring upstream and downstream subreaches, respectively. For run R5, the amounts of coarse sediments in the last two fractions (4.80 mm to 19.10 mm) were increased by 3% (keeping D_{50} unchanged) for sediment layers 4 ft below the bed in two subreaces near Sioux City (RM 732.3); this resulted in a slight decrease in degradation in the affected subreaches, accompanied by a slight increase in degradation in the downstream subreaches. In run R6, the bed-material size D_{50} was increased from 0.297 mm to 0.385 mm in a 58.5-mile reach (RM 684.15 to RM 742.65), with essentially the same result as for run R5 (in which only coarser fractions in subsurface layers 4 feet below were increased), but reductions and increases in degradation in the reach with coarser bed sediments and in downstream reaches, respectively, were of larger magnitudes.

The downstream boundary in run R9 was moved further downstream (48.75 miles d/s from Omaha) to study the effect of the downstream boundary condition (fixed water-surface elevation) on the degradation/aggradation pattern in the study reach. This change in downstream boundary location was found to have

insignificant influence on the overall degradation/ aggradation pattern in the study reach; but a significant effect was observed in the temporal bed evolution at particular locations in the lower half of the study reach. Run R10 is a 3-year simulation (1957-60) with improved boundary and initial conditions in an attempt to obtain better agreement with the observed drops in water-surface elevations due to the three cutoffs (DeSoto, California, and Middle-Lower Decatur) in the first three years; the predicted profile was indeed in better agreement, though not entirely satisfactory. In summary, the updated version of IALLUVIAL incorporates a realistic representation of bed armoring in the Missouri River reach from Gavins Point Dam to Omaha, as demonstrated by the reasonable agreement between the computed and observed changes after 20 years (1957-77) in water-surface profile (figure 21), and changes in bed-material composition and bed armoring (figures 25, 66 and 67).

V. SUMMARY AND CONCLUSIONS

The new version of IALLUVIAL incorporates extensive modifications of bed armoring procedures previously included in the program. The present procedure includes consideration of each sediment size fraction in armoring calculations, which permits removal or inclusion of a particular size fraction in the armor coat depending on the flow velocity and bed shear stress at a given time. The development of armoring by accumulation of non-movable particles on the bed surface of a plane bed (without bed forms) is first formulated from volumetric considerations as the fraction of unit bed area covered by armor coat, Eq. (16). The armoring coefficient, $C_A(t,k)$ in Eq. (16), is then modified to account for the effect of development and propagation of ripples and dunes, by relating dune height to the effectiveness of mixing processes caused by the formation and movement of these bed features. It was hypothesized that a very active bed, which was assumed to correspond to a flow condition with maximum dune height, will trap all the coarser immobile (or even slowly moving) particles at the bottom of the dunes, as illustrated by figure 4, the other extreme being the plane-bed case in which all non-moving particles accumulate on the surface, figure 3. The effect of dunes on the accumulation (or lack of it) of coarser particles on the bed surface is approximated by figure 5, or Eqs. (18) through (20). The stochastic nature of incipient motion of armoring particles is formulated by adopting Eq. (1) from Gessler's (1967) analysis, and Eq. (17).

IALLUVIAL, with the above bed armoring procedure incorporated, was applied to the 195-mile Missouri River reach between Gavins Point Dam and Omaha, Nebraska to simulate the 20-year changes in bed and water surface

profiles and bed-sediment composition since the closure of the Gavins Point Dam in 1957. Reasonable agreement was found between the observed and computed changes in water-surface elevations (figure 21), and changes in bed-material composition and bed armoring (figures 25, 66, and 67); agreement was, however, less satisfactory for the 3-year simulation (figure 76), probably due to approximations in specifying initial and boundary conditions, and the use of idealized rectangular cross-sections at large subreach intervals.

The sensitivity of the degradation/aggradation pattern in the study reach on channel cutoffs, changes in median bed-material size, and proportions of the coarser fractions in selected subreaches, was investigated in several simulation runs. It was found that the effect of three cutoffs--DeSoto, California and Middle-Lower Decatur--was significant in the rapid drop of water-surface elevations in these subreaches. A coarser bed sediment, with D_{50} increased from 0.297 mm to 0.385, or an increase by 3% in the amount of armoring fractions (4.80 mm to 19.10 mm), in some selected subreaches, were found to have significant effects in reducing degradation in the affected subreaches, accompanied by increased degradation in downstream reaches. Two alternative bed armoring procedures--the bed-layer procedure in which a thin active layer was assumed at the top of the mixed layer, and the surface-layer procedure in which surface-layer mean sediment size was computed as a function of armoring particle sizes and the mean size of the underlying mixed layer--were also investigated. It was assumed that the faster coarsening of the top layer (which is not the same as the armor layer), with this larger D_{50} used in sediment-discharge and friction-factor calculations, will indirectly account for the effects of bed armoring. The results presented in this study, however, show that neither of these procedures (bed-layer or surface-layer)

are adequate to simulate the evolution of bed and water-surface profiles, particularly the two-layer structure of the bed composition near the Gavins Point Dam (figure 67), of the Missouri River reach under study.

The results presented in this study were obtained from an idealized representation of the Missouri River reach by a regular two-stage upstream hydrograph, rectangular prismatic channel sections, and almost-constant bed-material size distributions throughout the reach. The space and time intervals (9.75 miles and 30 days) used in the simulation, dictated mainly by computer cost, are not adequate for representing widely varying cross-sectional properties, particularly in the uncontrolled reach between Gavins Point Dam and Ponca. In view of these limitations, and the fact that IALLUVIAL is a one-dimensional model which can only account for cross section-averaged quantities of interest, the reasonable agreement between the computed and observed values, as demonstrated by figures 21, 25, 66, and 67, is encouraging and suggests its usefulness in predicting long-term bed and water-surface evolutions of alluvial rivers, especially of the Missouri River.

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APPENDIX A

Input Data Format

Note: Superscript digits refer to notes at the end of the Appendix. Cards which are always required are marked by an asterisk (*).

	Card No.	Variable Name	Format & Column No.	Description and remarks
*	1	TITLE	15A4(1-60)	Title of the study
*	2	N	I5(1-5)	Number of computational points, or cross-sections
		N1	I5(11-15)	Number of sediment size intervals
		NT	I5(16-20)	Number of time steps
		MAXMA	I5(21-25)	Max. no. of elevations used to define cross-sections
		NTRIB	I5(41-45)	Number of tributaries; NTRIB ≥ 1 (upstream discharge is treated as a tributary)
		NBANK	I5(46-50)	Number of subreaches with erodible banks
		IBED	I5(51-55)	0 if vertically homogeneous bed material; 1 otherwise
*	3	MAXBED[1]	I5(1-5)	Maximum no. of nonhomogeneous vertical subsurface layers in a subreach
		IDREJ	I5(11-15)	0 if no dredging; 1 otherwise (required value = 0 presently)
		NTY	I5(16-20)	No. of time steps in a 360-day year
*	4	KDIA	I5(1-5)	Required value = 0
		IDIA	I5(6-10)	Required value = 0
		IUF	I5(11-15)	Required value = 0
		INPR	I5(16-20)	Frequency of printed output, in no. of time steps
		IROCK	I5(21-25)	0 if no rock outcrops; 1 otherwise
		IBUG[2]	I5(36-40)	0 for normal output; 1 for extensive diagnostic messages
		ICHB	I5(41-45)	0 for no width changes with time; 1 otherwise (required value = 0 presently)
		ICOFF	I5(46-50)	0 for no cutoffs with time; 1 otherwise (required value = 0 presently)
		NRES[3]	I5(56-60)	Results file reference number; 0 for no file

	Card No.	Variable Name	Format & Column No.	Description and remarks
*	5	IRES	I5(1-5)	Required value = 1
		ISED	I5(6-10)	Required value = 1
		INDEX	I5(11-15)	Required value = 1
		INDEX1	I5(16-20)	Required value = 0
		INDSS	I5(21-25)	Required value = 1
		ILIMIT	I5(26-30)	Required value = 5
		IEQ	I5(31-35)	Required value = 1
		IDSWS[4]	I5(36-40)	0 if downstream w.s. elev. given as input; 1 otherwise
*	6	ALFA	F10.4(1-10)	Parameter C_1 in Eq. (21)
		BETA	F10.4(11-20)	Parameter C_3 in Eq. (23)
		C21	F10.4(21-30)	Pqarameter C_2 in Eq. (22)
		C22	F10.4(31-40)	Required value = C21
		FMIX	F10.4(41-50)	Required value = 1.0
		CARM[5]	F10.4(51-60)	Parameter C_A in Eq. (15)
*	7	STR[6]	F14.7(1-14)	Energy slope for d.s. boundary and initial estimate
	8[7]	DMZ(I),I=1,N	6F10.4	Depth of rock outcrop below initial bed, by point
*	9	IUPS	I5(1-5)	0 for constant upstream sediment inflow; 1 for upstream sediment inflow rating curve
	10[8]	CPPMUP	F14.8(1-14)	Upstream sediment concentration, ppm
*	11	LOCTR(L),	12I5	Locations (point numbers) of tributaries, upstream
		L=1,NTRIB		to downstream. LOCTR(1) = N always
	12[9]	AC(L),BC(L)	2F14.8	Sediment rating curve coefficients, a_i, b_i in Eq. (26).
		L=1,NTRIB		One card for each tributary
*	13	PTRIB(L,K)	6F10.2	Probability distribution function for tributary
		K=1,N1; L=1,NTRIB		sediment loads; K varies first
	14[10]	IBSED	I5(1-5)	0 if eroded bank material size distribution same as bed; 1 if specified as input
		QMIN	F10.1(6-15)	Water discharge (cfs) below which no bank erosion occurs

Card No.	Variable Name	Format & Column No.	Description and remarks
15[10]	LOCBER(M), M=1,NBANK	12I5	Number of reaches subject to bank erosion, upstream to downstream
16[11]	PBANK(M,K) K=1,N1;M=1,NBANK	6F10.2	Probability distribution function for eroded bank material; K varies first, M varies upstream to downstream
17[10]	BEROS(M), M=1,NBANK	6F10.2	Bank erosion rates, ft^3/mile/day, in reaches LOCBER(M)
* 18	DS(K),K=1 N1+1	6F10.4	Sediment sizes (mm) delimiting the N1 size intervals

Card types 19,20 are read for each of N computation points, I=1, N, downstream to upstream; type 21 is read for each of (N-1) subreaches, downstream to upstream.

Card No.	Variable Name	Format & Column No.	Description and remarks
* 19	RMILE(I)	F10.2(1-10)	River mile of computational point I[12]
	MA(I)	I10(11-20)	Number of levels used to define cross section; MA(I) < MAXMA
* 20	STAGE(I,L)[13]	F10.3(1-10)	Reference elevation, ft
	AREA(I,L)[13]	F10.3(11-20)	Cross-sectional area, ft^2
	R1(I,L)	F10.3(21-30)	Hydraulic radius, ft
	B1(I,L)	F10.3(31-40)	Surface width, ft
	L=1,MA(I)		(lowest to highest level, one level per card)
* 21	CDF(K), K=1, N1+1	6F10.4	Cumulative distribution function for bed sediment in the reach between points I and I+1; CDF(K) corresponds to DS(K)
22[14]	NBEL(I) I=1,N-1	12I5	Number of elevations at which bed material changes in reach I, I from downstream to upstream
23[14]	THBED(I), I=1,N-1	6F10.3	Constant thickness (ft) of subsurface layers in reach I
24[15]	PBED(I,K,J), K=1,N1;J=1,NBEL; I=1,N-1		Probability distribution function for sediment in subsurface layer J of reach I
25	IBLR	I5(1-5)	0 for no bed layer; 1 if bed layer is used instead of armoring procedure (cards 26 and 27 are skipped if IBLR = 1)
	ISLR	I5(6-10)	0 if surface-layer procedure is not used; 1 if used

Card No.	Variable Name	Format & Column No.	Description and remarks
26	IARMOR	I5(1-5)	0 for direct specification of armoring size; 1 if calculated by the program
	MIND	I5(6-10)	Smallest sediment fraction number in armor coat (if IARMOR = 0)
	QMAX	F10.0(11-20)	If IARMOR=1, and IQMAX=0, constant discharge used to determine armoring size, cfs
	IQMAX	I5(21-25)	If IARMOR=1, 0 for determination of armor size based on QMAX, 1 if based on local hydrograph
	IACF	I5(26-30)	0 for no initial armored area; 1 if bed is armored initially
	KARM	I5(31-35)	0 for specifying constant value of armoring coefficient C_A in Eq. (16); 1 for using Gessler's relation; 2 for bed-load method; 3 for using both bed-load and Gessler's methods; 4 for dune-height method; 5 for using both Gessler's and dune-height method[16].
	C1	F10.4(36-45)	Coefficient for bed-load method (if KARM = 2 or 3).
27	ARM(I,K)	6F10.6(1-60)	Initial value of armor-covered bed area (fraction) for each sediment fraction K at reach I, downstream to upstream (K varies first); used only if IACF = 1.
28[17]	ITDAT	I4(1-4)	Date (day number) associated with the list of time-dependent data to follow
	TFREAD	F4.0(5-8)	Water temperature (°F) on day ITDAT
	QTRIB(L), L = 1, NTRLB	9F8.0(9-80)	Tributary water discharges (cfs) on day ITDAT (recall QTRIB(1) = mainstem inflow)
	YREAD		Downstream water level on day ITDAT (ft)
	QSREAD		Upstream sediment inflow (ppm) on day ITDAT

Notes

1. Used only if IBED=1.
2. The diagnostic messages are lengthy and of use only to the user who knows the detailed workings of the program.
3. NRES is the FORTRAN reference number of a sequential file onto which is written, without format, all results at each time step. This file can be used for off-line analysis of the computation.
4. If IDSWS=1, the program uses TLTM to compute the water surface elevation at the downstream boundary, for an imposed energy slope of STR (see Card 7).
5. The Missouri River model uses $C_A = 1.90$.
6. The Missouri River model uses STR=0.00189.
7. Card 8 is read only if IROCK=1.
8. Card 10 is read only if IUPS=0.
9. AC has units of tons/day; BC is dimensionless. AC(I), BC(I) are read only if IUPS=1.
10. Card(s) read only if NBANK ≠ 0.
11. Card 10 are read only if NBANK ≠ 0 and IBSED=1.
12. River miles increase from downstream to upstream, and must represent actual distances along the mainstem.
13. If AREA (I,MA(I)) is left blank, both the areas and hydraulic radii (average depths) will be calculated automatically by the trapezoidal rule. Otherwise the user must furnish consistent values.
14. Card(s) read only if IBED=1.
15. Card(s) read only if IBED = 1 and NBEL(I) ≠ 0.
16. The Missouri River model uses KARM = 5, which is recommended.
17. IALLUVIAL obtains time-dependent data by linear interpolation (in time) between successive data lists of type 28 cards. At least two type 28 cards are required; ITDAT < 0 on the first, ITDAT > NT*360/NTY on the last.
18. TFREAD is used only if IDSWS=0.

APPENDIX B

Program Listing

```
C     ******************************************
C
C        PROGRAM  I  A  L  L  U  V  I  A  L
C
C     ******************************************
C
C      DEFINITION OF VARIABLES
C
C      SECTION I,          I=1,N
C      SIZE FRACTION K,    K=1,N1
C      ELEVATION L,        L=1,MA(I)
C      TIME INTERVAL IT,   IT=1,NT
C
C      IRES= INDEX VARIABLE TO INDICATE METHOD OF COMP.FLOW RESISTANCE
C            IRES= 1 FOR IIHR METHOD ; IRES= 2 FOR A-L-K METHOD
C      ISED= INDEX VARIABLE TO INDICATE  METHOD OF COMPUTING SEDIMENT
C            DISCHARGE ; ISED= 1 FOR IIHR METHOD; ISED= 2 FOR EINSTEIN
C            METHOD
C      INDEX=INDEX VARIABLE TO INDICATE NO.OF SUBSECTIONS USED IN
C            BACKWATER CALCULATIONS (=1 FOR SINGLE CHANNEL,=2 FOR
C            2 SUBSECTIONS, =3 FOR 3 SUBSECTIONS )
C      INDEX1=INDEX VARIABLE TO INDICATE WHETHER NO. OF SUBCHANNELS
C             USED IN SEDIMENT CALCULATIONS IS THE SAME OR MORE THAN
C             THAT USED IN BACKWATER CALCULATIONS (=0,SAME; =1, MORE )
C      INDSS=INDEX VARIABLE TO SPECIFY UPSTREAM SEDIMENT DISCHARGE;
C            INDSS=0 IF COMPUTED BY THE PROGRAM AS EQUAL TO THE
C            TRANSPORT CAPACITY; =1 IF GIVEN AS INPUT
C      IDSWS=INDEX VARIABLE TO SPECIFY DOWNSTREAN WATER SURFACE
C             ELEVATION;IDSWS=0 IF GIVEN AS INPUT; =1 IF COMPUTED
C             INTERNALLY ASSUMING UNIFORM FLOW
C      N=NO. OF SECTIONS,IN LONGITUDINAL DIRECTION
C      N1=NO. OF SEDIMENT SIZE FRACTIONS
C      NT= NO. OF TIME INTERVALS
C      NTRIB=NUMBER OF TRIBUTARIES
C      NBANK= NUMBER OF REACHES WITH BANK EROSION
C      IBED = INDEX VARIABLE TO INDICATE VERTICAL VARIATION OF BED-MAT.
C               SIZE DIST. BELOW ORIGINAL CHANNEL BED; IBED=0 FOR NO
C               VARIATION; =1 FOR VARIATION.
C      NBED= NO. OF REACHES WHERE SEDIMENT-BED COMPOSITION VARIES
C              IN VERTICAL DIRECTION
C      NTP=NO.OF TIME INTERVALS AT WHICH BED-ELEVATION CHANGES WILL BE
C           PLOTTED AT A GIVEN SECTION
C      ICHB= INDEX VARIABLE FOR CHANGE IN CHANNEL WIDTH WITH TIME;
C               ICHB=0 FOR NO CHANGE; =1 FOR CHANGE.
C      ICOFF= INDEX VARIABLE FOR INCORPORATING CHANNEL CUTOFF AT
C                  SPECIFIED TIMES
C      IDREJ=INDEX VARIABLE FOR DREDGING; IDREJ=0 FOR NO DREDGING;
C                  =1 FOR DREDGING.
C      IBUG=INDEX VARIABLE FOR PRINTING DETAILED OUTPUT FOR DEBUGGING
C              IBUG=0 FOR NO PRINT; =1 FOR PRINTING .
C      ILIMIT=LIMITING NUMBER OF VIOLATIONS OF SPECIFIED CRITERIA FOR
C             RECOMPUTING BACKWATER PROFILE AND/OR SEDIMENT LOADS
C             IN EACH TIME PERIOD
C      IEQ= INDEX VARIABLE TO INDICATE EQUILIBRIUM OR NON-EQUILIBRIUM
C           SEDIMENT CALCULATIONS ( IEQ=1 FOR EQM., IEQ=0 FOR NON-EQM.)
C      IDELT=TIME INTERVAL,DAYS
C      NTY=NO. OF TIME STEPS IN ONE YEAR (360DAYS)
```

```
C       ITIME=TOTAL PERIOD,DAYS
C       GAMA=SPECIFIC WEIGHT(LBS/CFT) OF SEDIMENT
C       IFLAG=INDEX VARIABLE TO INDICATE RECOMPUTATION OF BACKWATER
C             PROFILE ( IFLAG=0: DO NOT RECOMPUTE; IFLAG=1: RECOMPUTE )
C       IFLAG1=INDEX VARIABLE TO INDICATE RECOMP. OF SEDIMENT LOADS
C               IN EACH TIME PERIOD (IFLAG1=0,DO NOT RECOMPUTE;
C               IFLAG1=1, RECOMPUTE )
C
C       MA(I)=NO.OF INDEX ELEVATIONS FOR COMPUTING GEOMETRIC PROPERTIES
C             AT SECTION I
C       STAGE(I)=WATER SURFACE ELEVATION AT SECTION I,IN TIME INT. IT
C       REACH(I)=LENGTH OF REACH(FT.) BETWEEN SECTIONS I AND I+1
C       Q(I)=TOTAL DISCHARGE(CFS.) AT SECTION I,IN TIME INTERVAL IT
C       STAGE1(I,L),AREA(I,L),R1(I,L),B1(I,L)=STAGE,AREA,HYD.RADIUS,AND
C             W.S.WIDTH ,RESPECTIVELY,OF THE WHOLE SECTION AT SECTION I,
C             ELEV. INDEX L
C       D50 (I)=MEDIAN SEDIMENT SIZE (MM) AT SECTION I
C       D65G(I)=D65(MM) AT SECTION I,SEGMENT J
C       DLIM(I)= MAXM. SEDIMENT DEPTH(FT) AT START ON BED AT SECTION I,
C                  SEGMENT J
C       D(K),P(K),W(K)=SED.SIZE(MM.),POROSITY,AND FALL VELOCITY(FT/S),
C                      RESPECTIVELY,FOR SIZE FRACTION K
C       PT(I,K)=SED. FRACTION FOR SECTION I,SEGMENT J,SIZE K,IN THE BED
C       PTT(I,K)=INITIAL VALUE OF PT(I,K)
C       PTI(I,K)=INITIAL STORAGE FOR PT(I,K)
C       TF(I),VISC(I)= ARRAY OF TEMPERATURE AND VISCOSITY OF WATER ,
C                      RESPECTIVELY, AT INDEX I
C       TEMPF= TEMPERATURE(F) OF WATER IN TIME PERIOD IT
C       GS(K)=SPECIFIC WEIGHT(LBS/CFT),FOR SIZE FRACTION K
C       SSC(I,K)=SED.CONCN.(PPM) OF FRACTION K,AT SEGMENT J,SECTION I
C       SS1(K)=SSC(N,K)
C       B(I)=W.S.WIDTH
C       SF(I)=ENERGY SLOPE
C       CTO(I)=MEAN SED. CONCENTRATION PER VOLUME, AT SECTION I
C       FR(I)=FRICTION FACTOR
C       PSD(K)=FRACTION OF MATERIAL OF SIZE K IN THE DISCHARGE
C       RA(I)=HYD. RADIUS AT SECTION I,SEGMENT J
C       XA(I)=CROSS SECTION AREA AT SECTION I,SEGMENT J
C       BB(I)=W.S.WIDTH
C       D50G(I)=SED.DIA.(MM.)  AT SECTION I, SEGMENT J
C       QST(I)=TOTAL DISCHARGE OF SEGMENT J,AT SECTION I
C       VAV(I)=MEAN VELOCITY AT SECTION I,SEGMENT J
C       SE(I)=ENERGY SLOPE AT SECTION I, SEGMENT J
C       DW(I)=MEAN WATER DEPTH OF SEGMENT J, AT SECTION I
C       DELDB (I,K)=CHANGE IN BED ELEVATION AT SECTION I, SEGMENT J, FOR
C                    SED. FRACTION K,DUE TO BED LOAD
C       DELDS (I,K)=CHANGE IN BED ELEVATION AT SECTION I, SEGMENT J, FOR
C                    SED. FRACTION K,DUE TO SUSPENDED LOAD
C       TDELD (I,K)=CHANGE IN BED ELEVATION AT SECTION I, SEGMENT J, FOR
C                    SED. FRACTION K,DUE TO SUSPENDED LOAD AND BED LOAD
C       CDEP(I)=SUM IN K AND TIME OF TDELD(I,K)
C
C       DYNAMIC ALLOCATION OF ARRAYS
C
C       ATTENTION : ARRAY T MUST ALWAYS BE DIMENSIONED T(MEMO)
C       ---------                ------
C
C               $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

```
                 DIMENSION T(20000   ),TITLE(15)
                 MEMO=20000
C               $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
       COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
      1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
C
       READ (5,1000) TITLE
 1000  FORMAT(15A4)
       WRITE(6,2000) TITLE
 2000  FORMAT('1',////,10X,70('*'),/,10X,'*',68X,'*',/,10X,'*',4X,
      $ 15A4,4X,'*',/,10X,'*',68X,'*',/,10X,70('*'),////)
C
C      READ DIMENSIONING PARAMETERS
C
       READ(5,1001) N,M1,N1,NT,MAXMA,NOBS,NX,IGR,NTRIB,NBANK,IBED,NBED
       READ(5,1001) MAXBED,NTP,IDREJ,NTY
 1001  FORMAT(12I5)
       NN=N-1
       NMA=N*MAXMA
       NN1=N*N1
       N1P1=N1+1
       NT3651=1
       NT3652=1
       IF (NTY.NE.0) NT3651=NT/NTY+1
       IF (NTY.NE.0) NT3652=NT/NTY+2
       NT1=1
       IF (NTP.NE.0) NT1=NT/NTP+2
C
C      DYNAMIC ALLOCATION OF WORKING ARRAYS WITHIN ARRAY T
C
       I1=1
       I2=I1+NN1
       I3=I2+NN
       I4=I3+N
       I5=I4+NN
       I6=I5+N*N1
       I7=I6+N
       I8=I7+N
       I9=I8+N*N1
       I10=I9+N
       I11=I10+NMA
       I12=I11+NMA
       I13=I12+NN
       I14=I13+NMA
       I15=I14+NMA
       I16=I15+NMA
       I17=I16+NMA
       I18=I17+NMA
       I19=I18+N1+1
       I20=I19+NN
       I21=I20+(N1+1)
       I22=I21+N
       I23=I22+N1
       I24=I23+N1
       I25=I24+NN*N1
       I26=I25+NN*N1
       I27=I26+72
```

```
I28=I27+NTRIB
I29=I28+N1
I30=I29+NN1
I31=I30+N1
I32=I31+NN*N1
I33=I32+N
I34=I33+N
I35=I34+N
I36=I35+N
I37=I36+N
I38=I37+N
I39=I38+N
I40=I39+N
I41=I40+N1
I42=I41
I43=I42
I44=I43
I45=I44
I46=I45
I47=I46
I48=I47+N
I49=I48+N
I50=I49+N
I51=I50+NN1
I52=I51+NN1
I53=I52+N
I54=I53+NN1
I55=I54+NN1
I56=I55+N
I57=I56+N
I58=I57+N
I59=I58+N
I60=I59+N
I61=I60+N*NTY
I62=I61
I63=I62+N
I64=I63+NN1
I65=I64
I66=I65
I67=I66+N
I68=I67
I69=I68
I70=I69
I71=I70
I72=I71
I73=I72
I74=I73+NN1
I75=I74+N
I76=I75+N
I77=I76+NN1
I78=I77+N
I79=I78+N
I80=I79+NN1
I81=I80+N
I82=I81+NN1
I83=I82+NN1
I84=I83+N
I85=I84+NN1
```

```
      I86=I85+N
      I87=I86+NTRIB
      I88=I87+NTRIB
      I89=I88+NTRIB*N1
      I90=I89+NTRIB
      I91=I90+NTRIB*N1
      I92=I91+NTRIB
      I93=I92+NTRIB
      I94=I93+NBANK
      I95=I94+NBANK
      I96=I95+NN
      I97=I96+NN
      I98=I97+(NN*N1*MAXBED)*IBED
      I99=I98+NT3651
      I100=I99+NT3651
      I101=I100+NT3651*N
      I102=I101+NT3651*NN
      I103=I102+NT3651
      I104=I103+NT3651
      I105=I104+NBANK*N1
      I106=I105+NN*N1
      I107=I106+NT*IDREJ
      I108=I107+NT*N*IDREJ
      I109=I108+NT*IDREJ
      I110=I109+N*IDREJ
      I111=I110+N
      IEND=I111
C
C     VERIFICATION OF SUFFICIENT MEMORY
C
      IF(IEND.LT.MEMO) GO TO 10
      CALL ERROR1( IEND,MEMO,N,M1,N1,NT,MAXMA,NOBS,NX,IGR)
C
C     MEMORY O.K. TRANSFER CONTROL AND ARRAY ADDRESSES TO SMAIN
C
10    WRITE(6,2002) IEND,MEMO
2002  FORMAT(T20,'MEMORY USED =',I8,' WORDS',3X,'MEMORY AVAILABLE=',I8)
      CALL SMAIN(TITLE,T(I1),T(I2),T(I3),T(I6),T(I7),
     1 T(I9),T(I10),T(I11),T(I12),T(I13),T(I14),T(I15),T(I16),
     2 T(I17),T(I18),T(I19),T(I20),T(I21),T(I22),T(I23),T(I24),T(I25),
     3 T(I26),       T(I28),T(I29),T(I30),T(I31),T(I32),T(I33),T(I34),
     4 T(I35),T(I36),T(I37),T(I38),T(I39),T(I40),T(I4))
       CALL SMAIN1 (T(I47),T(I48),T(I49),T(I50),T(I51),T(I52),
     6 T(I53),T(I54),T(I55),T(I56),T(I57),
     7 T(I62),T(I63),T(I66),
     8 T(I73),T(I74),T(I75),T(I76),T(I77),T(I78),T(I79),
     9 T(I80),T(I81),T(I82),T(I83),T(I84),T(I85),T(I86),T(I87),T(I88),
     8 T(I89),T(I90),T(I91),T(I92),T(I93),T(I94),T(I95),T(I96),T(I97),
     9 T(I98),T(I99),T(I100),T(I101),T(I102),T(I103),T(I104),T(I105),
     @ T(I106),T(I107),T(I108),T(I109),T(I110),T(I5),T(I8),
     $ T(I58),T(I59),T(I60),T(I27))
      STOP
      END
C
C
C
C     ----------------------
C        SUBROUTINE  SMAIN
```

```
C     --------------------
C
      SUBROUTINE SMAIN (TITLE,VOLIN,REACH,DMZ,STAGE,Q,
     1 MA,STAGE1,B1,SL1,R1,AREA,AREAI,RI,STAGEI,DS,D50,CDF,DMS,P,D,
     2 PT,PTT,TF,W,SSC,SS1,PTI,XAREA,R,B,CTO,SF,ACF,CIN,FR,GS,QSDP)
C
      INTEGER ICODE/'IAL1'/
      LOGICAL SECCAL
      DIMENSION VOLIN(N,N1),REACH(NN),TITLE(15),DMZ(N),
     1 STAGE(N),Q(N),MA(N),STAGE1(N,
     2 MAXMA),B1(N,MAXMA),SL1(NN),R1(N,MAXMA),AREA(N,MAXMA),AREAI(N,
     3 MAXMA),RI(N,MAXMA),STAGEI(N,MAXMA),DS(N1P1),D50(NN),CDF(
     4 N1P1),DMS(N),P(N1),D(N1),PT(NN,N1),PTT(NN,N1),TF(72),
     5 VISC(72),W(N1),SSC(N,N1),SS1(N1),PTI(NN,N1),XAREA(N),
     6 R(N),B(N),CTO(N),SF(N),ACF(N),CIN(N),FR(N),GS(N1),
     7 VAV(N),QSDP(NN),QTRIB(NTRIB),
     8 SE(N),DW(N),DELDS(N,N1)
      DIMENSION TDELD(N,N1),CDEP(N),KA(N,N1),        Y(N),
     1 VOLOUT(N),RMILE(N),LLIM(N),DELT(N,
     2 N1),DH(N),ARM(N,N1),PAC(N,N1),D50SL(N),D50SLS(N),WSEL(N,NTY),
     3 TI(N,N1),TH(N),TH1(N),PTP(N,
     4 N1),EL1(N),EL2(N),PTU(N,N1),BML(N),PQS(N,N1),PDN(N,
     5 N1),CDEP1(N),TB(N,N1),ACF1(N),BZ(N,N1),
     6 QTR(NTRIB),QSTR(NTRIB),TDELTR(NTRIB,N1),LOCTR(NTRIB),
     7 PTRIB(NTRIB,N1),AC(NTRIB),BC(NTRIB),LOCBER(NBANK),
     8 BEROS(NBANK),NBEL(NN),THBED(NN),PBED(NN,N1,MAXBED)
      DIMENSION ICHBT(NT3651),ICOFFT(NT3651),ICHBL(NT3651,N),
     1 ICOFFL(NT3651,NN),NCHBL(NT3651),NCOFFL(NT3651),
     2 PBANK(NBANK,N1),
     3 PTA(NN,N1),IDRT(NT),IDRL(NT,N),NDRL(NT),VDREJ(N),DARM(N)
      DATA VISC /1.92,1.89,1.85,1.82,1.79,1.76,1.72,1.69,1.66,1.64,
     &1.61,1.58,1.55,1.53,1.50,1.48,1.45,1.43,1.41,1.39,1.37,1.34,
     & 1.32,1.30,1.28,1.26,1.25,1.23,1.21,1.19,1.17,1.16,1.14,1.13,
     & 1.11,1.10,1.08,1.07,1.05,1.04,1.03,1.01,.999,.986,.974,.961,
     & .949,.938,.926,.915,.904,.893,.883,.873,.862,.852,.843,.833,
     & .824,.814,.805,.796,.788,.779,.771,.762,.754,.746,.738,.731,
     & .723,.716 /
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
      COMMON/DREJ/KDREJ
      COMMON/ARM1/IBLR,ISLR,FSLR
C
      RETURN
      ENTRY SMAIN1(VAV,SE,DW,DELDS,TDELD,CDEP,KA,BZ,Y,
     4 VOLOUT,RMILE,LLIM,DELT,DH,
     5 TI,TH,TH1,PTP,EL1,EL2,PTU,BML,PQS,PDN,CDEP1,TB,ACF1,
     6 QTR,QSTR,TDELTR,LOCTR,PTRIB,AC,BC,LOCBER,BEROS,NBEL,THBED,PBED,
     7 ICHBT,ICOFFT,ICHBL,ICOFFL,NCHBL,NCOFFL,PBANK,PTA,IDRT,IDRL,
     8 NDRL,VDREJ,DARM,ARM,PAC,D50SL,D50SLS,WSEL,QTRIB)
C
C
C     DATA INPUT
C
C      IFR=INDEX VARIABLE TO INDICATE MODE OF CALCULATING FR. FACTOR
C          IFR=0 FOR CONSIDERING FR.FR. AS FUN. OF QS IN CURRENT PERIOD
```

```
C          IFR=1 FOR CONSIDERING FR.FR. AS FUN. OF QS IN PREVIOUS PERIOD
C      IDIA=INDEX VARIABLE TO INDICATE PROCEDURE OF FINDING D50 AT
C               A SECTION FROM ADJACENT REACH VALUES
C              IDIA=0 FOR CALCULATING D50 BY AVERAGING ADJ. REACH VALUES
C              IDIA=1 FOR CALCULATING D50 AS THE U/S REACH VALUE
C      IUF=INDEX VARIABLE TO INDICATE PROC. TO SPECIFY W.S. ELEVATION
C                AT THE MOST D/S SECTION
C              IUF=0 FOR SPECIFIED W.S.ELEV. AT THE MOST D/S SECTION
C              IUF=1 FOR CALCULATING W.S.ELEV. FOR UNIFORM FLOW
C      INPR=INDEX VARIABLE TO INDICATE FREQUENCY(@ NO. OF TIME INTERVALS)
C               OF PRINTING RESULTS
C      KDIA=INDEX VARIABLE FOR CONSIDERING ARMORING EFFECT IN CALC. D50
C              KDIA=0 FOR NOT CONSIDERING ARMORING EFFECT
C              KDIA=1 FOR CONSIDERING ARMORING EFFECT
C      IGR=INDEX VARIABLE TO INDICATE PLOTTING OPTION
C              IGR=0 FOR NO PLOT ; IGR=1 FOR PLOT
C      IPLOT=INDEX VARIABLE FOR TYPE OF PLOTS; IPLOT=0 FOR PLOTTING
C              ABSOLUTE VALUES OF BED W.S. ELEVATIONS; =1 FOR PLOTTING
C              INCREMENTAL CHANGES IN BED AND W.S. ELEVATIONS
C      IROCK=INDEX VARIABLE FOR LIMITING DEGRADATION DUE TO ROCK OUTCROP
C              IROCK=0 FOR NO ADJUSTMENT DUE TO ROCK OUTCROP
C              IROCK=1 FOR ADJUSTMENT DUE TO ROCK OUTCROP
C
C      IOBS=INDEX VARIABLE FOR INCLUDING OBSERVED CHANGE IN W.S.
C             PROFILE IN PLOTS
C              IOBS=0 FOR NOT INCLUDING OBSERVED VALUES
C              IOBS=1 FOR INCLUDING OBSERVED VALUES
C      INPUT=INDEX VARIABLE TO DESCRIBE DATA INPUT
C              INPUT=0 FOR SIMLIFIED DATA INPUT FOR THE MO. RIVER
C              INPUT=1 FOR GENERAL DATA INPUT
C
C      READ CONTROL VARIABLES
C
       READ(5,2) KDIA,IDIA,IUF,INPR,    IROCK,IOBS,INPUT,IBUG,ICHB,ICOFF
      @   ,IPLOT,NRES
C
C       OPEN RESULTS FILE,WRITE GENERAL DATA ON IT
C
       IF (NRES.GT.0) WRITE(NRES)ICODE
       IF (NRES.GT.0) WRITE(NRES)TITLE
       IF (NRES.GT.0)WRITE(NRES)
      1N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
      2 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
       READ(5,1) IRES,ISED,INDEX,INDEX1,INDSS, ILIMIT,IEQ,IDSWS
C
C      READ CALIBRATION PARAMETERS AND DIVERSE PHYSICAL PARAMETERS
C
       READ(5,5) ALFA,BETA,C21,C22,FMIX,CARM
       READ(5,3) STR,RMDS
       SF(1)=STR
       IF(IROCK.EQ.1) READ(5,5) (DMZ(I),I=1,N)
       IDELT=360/NTY
       IFR=0
       WRITE(6,54) IRES,ISED,INDEX,INDEX1,INDSS, N,M1,N1,NT,ILIMIT,IEQ,
      *    IFR,IDIA,IUF,INPR,KDIA,IGR,IROCK,IOBS,INPUT,NTRIB,NBANK,
      *    IBED,NBED,MAXBED,MAXMA,NOBS,NX,NTP,IBUG,ICHB,ICOFF,IPLOT,
      *    IDREJ,NTY,IDSWS,IDELT,NRES
       WRITE(6,31) ALFA,BETA,C21,C22,FMIX,CARM
```

```
      WRITE(6,29) STR,RMDS
C
C      CALL TRIB TO READ TRIBUTARY DATA
C
      CALL TRIB(QTR,QSTR,TDELTR,LOCTR,PTRIB,AC,BC,Q,LOCBER,BEROS,
     @  PBANK,CTO,INPUT)
C
      NN1=N1+1
C
C     READ STANDARD SEDIMENT SIZES
C
      READ(5,5) (DS(K),K=1,NN1)
      WRITE(6,20)
C
C      READ SECTION DATA, COMPUTE RIVER MILES,AREAS, HYDRAULIC
C      RADII (LAST AREA=0.0 INTERPRETED AS REQUEST TO CALCULATE
C      ALL AREAS )
C
      DO 100 I=1,N
4110  FORMAT (F10.2,I10)
      READ (5,4110) RMILE(I), MA(I)
      IF (I.GT.1) REACH(I-1)=(RMILE(I)-RMILE(I-1))*5280.0
      MM=MA(I)
      IF(MM.GT.MAXMA) CALL ERROR2(I,MM   ,MAXMA)
      WRITE (6,8) I,RMILE(I),MA(I)
      READ(5,4) (STAGE1(I,L),AREA(I,L),R1(I,L),
     1                         B1(I,L),L=1,MM)
      SECCAL=.TRUE.
      IF(AREA(I,MM).NE.0.) SECCAL=.FALSE.
      DO 312 L=1,MM
      IF(L.EQ.1.OR..NOT.SECCAL) GO TO 750
      AREA(I,L)=AREA(I,L-1)+0.5*(B1(I,L-1)+B1(I,L))
     1          *(STAGE1(I,L)-STAGE1(I,L-1))
      R1(I,L)=AREA(I,L)/B1(I,L)
750   AREAI(I,L)=AREA(I,L)
      RI(I,L)=R1(I,L)
      STAGEI(I,L)=STAGE1(I,L)
312   CONTINUE
      WRITE(6,16)(STAGE1(I,L),AREA (I,L),R1 (I,L),B1(I,L),L=1,MM)
      IF (I.EQ.N) GO TO 100
C
C     READ SEDIMENT CHARACTERISTICS FOR REACH
C
      READ(5,5) (CDF(K),K=1,NN1)
C
C     COMPUTE D50 FROM GIVEN CDF
C
      DO 25 K=1,NN1
         IF (CDF(K).GT.0.5) GO TO 35
25    CONTINUE
      K=NN1
35    D50(I)=DS(K-1)+(DS(K)-DS(K-1))*(0.5-CDF(K-1))/
     1 (CDF(K)-CDF(K-1))
C
C     TRANSLATE 'D50' FROM REACH TO SECTION
C
      IF (I.NE.1) DMS(I)=(D50(I)+D50(I-1))/2.0
      IF(IDIA.EQ.1) DMS(I)=D50(I)
```

```
      DO 108 K=1,N1
      P(K)=0.40
      D(K)=SQRT(DS(K)*DS(K+1))
      PT(I,K)=CDF(K+1)-CDF(K)
108   PTT(I,K)= PT(I,K)
      WRITE(6,1490) I,D50(I)
     1             ,(CDF(K),K=1,NN1)
      WRITE(6,61)(PT(I,K),K=1,N1)
C
C      INITIALIZE QSDP FOR REACH I
C
      QSDP(I)=0.0
100   CONTINUE
C
C      WRITE RIVER MILES ON RESULTS FILE
C
      IF(NRES.GT.0) WRITE(NRES) (RMILE(I),I=1,N)
      DMS(1)=D50(1)
      DMS(N)=D50(N-1)
C
C      GENERATE STANDARD TEMPERATURES FOR VISCOSITY TABLE
C
      N3=72
      TF(1)=32.0
      DO 203 I=2,N3
203   TF(I)=TF(I-1)+1.0
C
C      CALL SEDBED TO READ DATA ON VERTICAL VARIATION OF BED
C      SEDIMENT COMPOSITION
C
      IF(IBED.EQ.1) CALL SEDBED(NBEL,THBED,PBED)
C
C
C     CALCULATION OF UNIT WEIGHTS OF SEDIMENT FRACTIONS
C
      G1=30.0
      G2=65.0
      G3=93.0
      DO 211 K=1,N1
      A=D(K)
      IF(A.LE..004 ) GS(K)=G1
      IF(A.GT..004 .AND.A.LE..062 ) GS(K)=G2
      IF(A.GT..062                ) GS(K)= G3
211   CONTINUE
C
C      PRINT DIVERSE GENERAL DATA
C
204   WRITE(6,44)(REACH(I),I=1,NN)
      IF(IROCK.EQ.1) WRITE(6,30)
      IF(IROCK.EQ.1) WRITE(6,33) (DMZ(I3),I3=1,N)
      WRITE(6,48)(P(K),K=1,N1)
      WRITE(6,79) (DS(K),K=1,NN1)
      WRITE(6,62)
      WRITE(6,37)( D(K),K=1,N1)
      WRITE(6,121)
      WRITE(6,33)(TF(I),I=1,N3)
      WRITE(6,122)
      WRITE(6,37 )(VISC(I),I=1,N3)
```

```
      WRITE(6,88)
C
C     CONVERSION OF VISC(I) TO (SQ.FT./S)
C
      DO 935 I=1,N3
935   VISC(I)=VISC(I)*1.E-5
C
C     CONVERSION OF SED. SIZE FROM MM TO FT.
C
      DO 111 K=1,NN1
      IF (K.NE.NN1) D(K)=D(K)/304.8
111   DS(K)=DS(K)/304.8
      DO 814 I=1,N
      DMS(I)=DMS(I)/304.8
      IF(I.EQ.N) GO TO 814
      D50(I)=D50(I)/304.8
814   CONTINUE
C
C
C     INITIAL SUBROUTINE CALLS TO TRANSMIT ARRAY ADDRESSES
C
      CALL DAWATP(REACH,STAGE,Q,STAGE1,D,XAREA,R,B,CTO,SF,FR,ACF,
     1 LOCTR,QTR,DMS,D50SLS)
      CALL DARESI(Q,DMS,D,XAREA,R,CTO,SF,ACF,CIN,D50SLS)
      CALL DATRAS(D50,D,PT,SSC,R,CTO,SF,PQS,PDN,PAC)
      CALL DASECP(STAGE,MA,STAGE1,B1,R1,AREA,XAREA,R,B)
      CALL DASLOA(REACH,P,D,PT,PTT,SSC,CTO,SF,ACF,R,B,DW,
     1 DELDS,TDELD,CDEP,KA,VOLOUT,DELT,PQS,PDN,CDEP1,TB,ACF1,
     2 LOCTR,QSTR,PTRIB,TDELTR,LOCBER,BEROS,PBANK,Q,PTA,    D50,
     3 THBED,NBEL,STAGE1,PBED,DARM,EL1,VAV,QSDP)
      CALL DAHYSO(VOLIN,STAGE1,D50,P,PT,PTT,SSC,CTO,SF,ACF,R,BZ,
     1 TDELD,VOLOUT,LLIM,DELT,TI,TH,TH1,PTP,EL1,EL2,PTU,BML,TB,NBEL,
     2 THBED,PBED,CDEP,D,D50SL)
      CALL DAARMO(ACF,ACF1,PT,D,P,CDEP,PTT,VOLOUT,B,SF,D50,THBED,
     1            PTA,NBEL,STAGE1,PBED,Q,R,DARM,EL1,ARM,PAC,TDELD)
      IF(ICHB.EQ.1.OR.ICOFF.EQ.1)CALL DACHAN (ICHBT,ICOFFT,ICHBL,
     @ ICOFFL,REACH,B1,AREA,NCHBL,NCOFFL,MA,R1,ARM,PAC,TDELD)
      IF(IDREJ.EQ.1) CALL DADRED (IDRT,IDRL,NDRL,VDREJ,REACH,B,STAGE1,
     @ CDEP,AREA,R1,NBEL,THBED,PT,PTT,PBED,DARM,EL1,MA)
C
C      D50  CALCULATIONS FOR SURFACE LAYER
C
      DO 915 I=1,NN
      D50SL(I)=D50(I)*(1.0-ACF(I))
      DO 915 K=1,N1
      D50SL(I)=D50SL(I)+ARM(I,K)*D(K)
915   CONTINUE
      DO 916 I=1,N
916   IF(I.NE.1) D50SLS(I)=(D50SL(I)+D50SL(I-1))/2.0
      D50SLS(1)=D50SL(1)
      D50SLS(N)=D50SL(N-1)
C
C     BEGIN LOOP ON TIME STEPS
C
      IFLAG=0
      ITIME=0
      KYR=0
      DO 5000 IT=1,NT
```

```
      ITIME=ITIME+IDELT
C
C     LOAD NEW DISCHARGES,TEMPERATURE,AND D/S STAGE(IF IDSWS.NE.1)
C
      CALL INFLOW(Q,QTR,LOCTR,TEMPF,STAGE,CPPMUP,QTRIB)
C
C     COMPUTE NEW TRIBUTARY SEDIMENT LOADS
C
      CALL TRIBQS
C
C      LOAD D/S BOUNDARY CONDITION
C
      IF (IDSWS.EQ.1) CALL START(STAGE,Q,STAGE1,DMS,B,XAREA,MA,B1,
     @ R1,REACH,SF,AREA)
      KDREJ=0
C
C      CALL DREDGE TO EXECUTE DREDGING
C
      IF (IDREJ.EQ.1) CALL DREDGE
C
C     CALCULATE VISCOSITY FROM GIVEN TEMPERATURE IN EACH TIME PERIOD
C
      DO 900 I=1,N3
      IF(TEMPF.LE.TF(I)) GO TO 910
900   CONTINUE
      CALL ERROR3(IT,ITIME,TEMPF,TF(N3))
      I=N3
910   VIS=VISC(I)
      VISLOG=ALOG10(VIS)
C
C     ESTIMATING FALL VELOCITY BY RUBEY EQN.
C
      DO 214 K=1,N1
      F11=36.0*VIS**2/(32.2*D(K)**3*1.65)
      F1=SQRT(2.0/3.0+F11)-SQRT(F11)
      W(K)=F1*SQRT(1.65*32.20*D(K))
      IF(IBUG.EQ.1) WRITE(6,34) K,W(K)
34    FORMAT(10X,'W(',I2,')=',F10.4,'  (FT/S)')
214   CONTINUE
C
C
102   IPRINT=2
      IF(IT.LE.2) INTP=1
      IF(IT.GT.2) INTP=INPR
      IF(ITIME.EQ.360) INTP=1
      IF((IT/INTP)*INTP.NE.IT) IPRINT=0
      IF(IT.EQ.NT) IPRINT=2
C
C     CALL TO WATPRO FOR BACKWATER COMPUTATION IN EACH TIME STEP
C
      CALL WATPRO
C
C     CALCULATION OF MAIN FLOW PROPERTIES AT EACH SECTION
C
      DO 700 I=1,N
      VAV(I)=Q(I)/XAREA(I)
      SE(I)=FR(I)*(VAV(I)**2)/(8.0*32.2*R(I))
      DW(I)=XAREA(I)/B(I)
```

```
700   CONTINUE
C
C      CALL TO SLOAD FOR SEDIMENT CONTINUITY COMPUTATION
C
      CALL SLOAD
C
C
C     MODIFICATION OF SECTION PROPERTIES AFTER SEDIMENTATION IN EACH
C           TIME PERIOD
C
      DO 726 I3=2,NN
726   Y(I3)=(CDEP(I3-1)+CDEP(I3))/2.0
      Y(1)=CDEP(1)
      Y(N)=CDEP(N-1)
C
C     MODIFICATION BECAUSE OF ROCK OUTCROP
C
      IF(IROCK.EQ.0) GO TO 737
      DO 736 I3=1,N
736   IF(Y(I3).GT.DMZ(I3)) Y(I3)=DMZ(I3)
737   CONTINUE
C
C     MODIFICATION BY CHANGING INDEX ELEVATIONS OF X-SECTIONS
C
      DO 720 I=1,N
      MM=MA(I)
      DO 720 L=1,MM
      STAGE1(I,L)=STAGEI(I,L)-Y(I)
720   CONTINUE
C
C     TRANSLATE D50(I)  AND ACF(I) FROM REACHES TO SECTIONS
C
      IF(IBUG.EQ.1) WRITE(6,711) (ACF(I),I=1,NN)
711   FORMAT(5X,'ACF :  ',8E12.5)
      ACF(1)=ACF(1)
      ACF(N)=ACF(N-1)
      DMS(1)=D50(1)
      DMS(N)=D50(N-1)
      D50SLS(1)=D50SL(1)
      D50SLS(N)=D50SL(N-1)
      DO 731 I=1,NN
      DH(I)=ACF(I)
      IF (I.EQ.1) GO TO 731
      DMS(I)=(D50(I)+D50(I-1))/2.0
      D50SLS(I)=(D50SL(I)+D50SL(I-1))/2.0
      IF(IDIA.EQ.1) DMS(I)=D50(I)
      ACF(I)=( DH(I)+ DH(I-1))/2.
731   CONTINUE
      IF(IBUG.EQ.1) WRITE(6,711) (ACF(I),I=1,N )
C
      IF(IBUG.EQ.0) GO TO 5021
713   WRITE(6,82) ITIME
      DO 725 I=1,N
      WRITE(6,27) I
      DO 725 L=1,MM
      WRITE(6,84)STAGE1(I,L),AREA(I,L),R1(I,L)
725   CONTINUE
C
```

```
C     PRINT OUT RESULTS
C
 5021  YR=ITIME/365.0
      N2=NTP*IDELT
      NLINE=27
      N5=N/NLINE+1
      N6=1
      N7=N6+NLINE-1
      IF(N7.GT.N) N7=N
      IT1=IT*IDELT
      IDAY=IT1-KYR*360
      IF((IT1/360)*360.EQ.IT1) KYR=KYR+1
C
C      WRITE TIME HEADING ON RESULTS FILE
C
      IF(NRES.GT.0) WRITE(NRES) IT,ITIME,IDAY,KYR
      DO 811 I3=1,N5
      IF (IPRINT.NE.0) WRITE(6,70) ITIME,YR
      IF (IPRINT.NE.0) WRITE(6,71)
      DO 810 I1=N6,N7
      I=N+1-I1
      DMM=DMS(I)*304.8
      DSLMM=D50SLS(I)*304.8
      DEP=Q(I)/(B(I)*VAV(I))
      FFR=8.0*32.2*DEP*SE(I)/(VAV(I)**2)
      IF(IT.LE.NTY) WSEL(I,IT)=STAGE(I)
      ITA=IT-(IT/NTY)*NTY
      IF(ITA.EQ.0) ITA=NTY
      DWS=0
      IF(IT.GT.NTY) DWS=WSEL(I,ITA)-STAGE(I)
      CBAR=CTO(I)*2.65E6
      IF(I.EQ.N) GO TO 809
      IF(IPRINT.NE.0.AND.LLIM(I).EQ.0) WRITE(6,75) VOLOUT(I)
      IF(IPRINT.NE.0.AND.LLIM(I).EQ.1) WRITE(6,76) VOLOUT(I)
809   IF (IPRINT.NE.0) WRITE (6,72)
     1 I,RMILE(I),B(I),STAGE(I),Q(I),DEP,VAV(I),
     2 SE(I),Y(I),DSLMM, STAGE1(I,1),DMM,ACF(I),CBAR,FFR,DWS
      IF (NRES.LE.0) GO TO 810
C
C     WRITE CURRENT VALUES ON RESULTS FILE
C
      WRITE (NRES) B(I),STAGE(I),Q(I),DEP,VAV(I),SE(I),
     1Y(I),DSLMM,STAGE1(I,1),DMM,ACF(I),CBAR,DWS
      WRITE (NRES) (PT(I,K),K=1,N1)
810   CONTINUE
      N6=N7+1
      N7=N6+NLINE-1
      IF(N7.GT.N) N7=N
      IF (N6.GT.N7) GO TO 105
811   CONTINUE
105   IF (NRES.GT.0) WRITE(NRES) (QTR(I),I=1,NTRIB),
     1(QSTR(I),I=1,NTRIB)
C
C     RECALCULATION OF SEDIMENT DIA. AFTER SEDIMENTATION IN EACH PERIOD
C
4560  DO 1110 I=1,NN
      CDF(1)=0.0
      DO 1112 K=2,NN1
```

```
      IF(IBLR.EQ.0) CDF(K)=CDF(K-1)+PT(I,K-1)
      IF(IBLR.EQ.1) CDF(K)=CDF(K-1)+PAC(I,K-1)
      IF(CDF(K).GE.0.50) GO TO 1113
1112  CONTINUE
1113  D50(I)=DS(K-1)+(0.50-CDF(K-1))/(CDF(K)-CDF(K-1))
     *    *(DS(K)-DS(K-1))
      IF(CDF(K).EQ.0.50) D50(I)=DS(K)
      D50MM=D50(I)*304.8
      IF(IBUG.EQ.1) WRITE(6,1111) I,D50MM,(PT(I,K),K=1,N1)
1111  FORMAT(5X,'I=',I3,2X,'D50=',F6.3,2X,'PT:   ',9F9.5)
1110  CONTINUE
C
C        D50  CALCULATION FOR SURFACE LAYER
C
      DO 1125 I=1,NN
      D50SL(I)=D50(I)*(1.0-ACF(I))
      DO 1125 K=1,N1
      D50SL(I)=D50SL(I)+ARM(I,K)*D(K)
1125  CONTINUE
C
C     TRANSLATES D50 FROM REACH TO SECTION
C
      DMS(1)=D50(1)
      DMS(N)=D50(N-1)
      D50SLS(1)=D50SL(1)
      D50SLS(N)=D50SL(N-1)
      DO 728 I=2,NN
      DMS(I)=(D50(I)+D50(I-1))/2.0
      D50SLS(I)=(D50SL(I)+D50SL(I-1))/2.0
      IF(IDIA.EQ.1) DMS(I)=D50(I)
728   CONTINUE
C
C
C     CALCULATING MAXM. VALUE OF TIME INTERVAL WHICH WILL NOT VIOLATE
C        SEDIMENT CONTINUITY THROUGH REACHES
C
4999  DMIN=DELT(1,1)
      IF(IT.EQ.1) NVI=0
      IF(IT.EQ.1) VDEGR=0
      IF(IT.EQ.1) VDEGRP=0
      VPROF=0
      DO 753 I1=1,NN
      CONN=REACH(I1)*(B(I1)+B(I1+1))/2.0*(1.0-P(1))
      VDEGR=VDEGR+VOLOUT(I1)*CONN
      VPROF=VPROF+(Y(I1)+Y(I1+1))/2.0*CONN
      DO 753 K1=1,N1
      DINT=FLOAT(IDELT)
      IF(DINT.GT.DELT(I1,K1)) NVI=NVI+1
      IF(DELT(I1,K1).GE.DMIN) GO TO 753
      DMIN=DELT(I1,K1)
753   CONTINUE
      VT1=VDEGR*(2.65*62.5/2000.)/(ITIME/365.0)
      VT2=VPROF*(2.65*62.5/2000.)/(ITIME/365.0)
      VT3=(VDEGR-VDEGRP)*(2.65*62.5/2000.)/(IDELT/365.0)
      VDEGRP=VDEGR
      IF(IPRINT.EQ.2) WRITE(6,43) DMIN,NVI,VDEGR,VT1,VPROF,VT2,VT3
43    FORMAT(   /,15X,70('*'),/,15X,'*',68X,'*',/,15X,'*',68X,'*',
     * /,15X,'*',9X,'MAXM. VALUE OF TIME INTERVAL WHICH WILL NOT ',
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     * 'VIOLATE',8X,'*',/,15X,'*',23X,'SEDIMENT CONTINUITY IS',
     * 23X,'*',/,15X,'*',28X,F6.2,2X,'DAYS',28X,'*',/,15X,'*',
     * 28X,13('-'),27X,'*',/,15X,'*',20X,'TOTAL NO. OF VIOLATIONS =',
     * I4,19X,'*',         /,15X,'*',68X,'*',/,15X,'*'
     *    , 3X,'DEGR.VOL.(SED.CONT.) =',E12.5,2X,'CFT',' (',E12.5,2X,
     *    'TONS/YR )',T85,'*',/,15X,'*',
     *    , 3X,'DEGR.VOL.(PROFILE)   =',E12.5,2X,'CFT',' (',E12.5,2X,
     *    'TONS/YR )',T85,'*',/,15X,'*',
     * 68X,'*',/ ,15X,'*',13X,'CURRENT SCOUR RATE =',E12.5,
     * '   TONS/YR',T85,'*',/,15X,'*',68X,'*',/,15X,70('*'),//)
5000  CONTINUE
      WRITE(6,7)
C
C
1     FORMAT(10I5)
749   FORMAT(11I5)
2     FORMAT(12I5)
3     FORMAT(2F14.7)
4     FORMAT(4F10.3)
5     FORMAT(6F10.4)
6     FORMAT(8F10.4)
7     FORMAT('1')
8     FORMAT(//,5X,'SECTION',I3,' RMILE=',F7.2,
     @    ' MA=',I3,T40,'STAGE',9X,'AREA',11X,
     1         'HYD. RAD.',5X,'SURF. WIDTH',/,T05,93(1H-))
9     FORMAT(20X,'NO. OF SECTIONS=',I3,//)
10    FORMAT(///,20X,'NO. OF SUBCHANNELS =',I5,//)
11    FORMAT(10X,'WHOLE SECTION',//,6X,'STAGE',9X,'AREA',11X,'HYD. RA
     *D.',5X,'WAT.SUR.WIDTH',/)
12    FORMAT(/,5X,'DHO(L,I)',/)
13    FORMAT(/,5X,'D50(I)',/)
14    FORMAT(15A4)
15    FORMAT('1',////,10X,70('*'),/,10X,'*',68X,'*',/,10X,'*',4X,
     $ 15A4,4X,'*',/,10X,'*',68X,'*',/,10X,70('*'),////)
16    FORMAT((T37,4(F10.3,5X)))
17    FORMAT(/,15X,'D50 =',F6.4,1X,'MM.')
18    FORMAT(20X,'REACH LENGTHS(FT.) :',/)
19    FORMAT(25X,'REACH..',I3,':',2X,F10.2,/)
20    FORMAT(///)
21    FORMAT(20X,'DISCHARGE(CFS) :',/)
22    FORMAT(30X,8F10.0)
23    FORMAT(/,5X,'ITOB(L)',/)
30    FORMAT(/,5X,'DMZ(I)',/)
31    FORMAT(//,5X,'ALFA=',F6.3,2X,'BETA=',F6.3,2X,'C21=',F6.3,
     #  2X,'C22=',F6.3,2X,'FMIX=',F6.3,2X,'CARM=',F6.3,//)
33    FORMAT (15X,8F10.1)
51    FORMAT(3F10.4)
53    FORMAT(/,5X,'Q(NI)')
54    FORMAT(     //,5X,'IRES=',I1,2X,'ISED=',I1,3X,'INDEX=',I1,3X,
     @'INDEX1=',I1,3X,'INDSS=',I1,4X,'N=',I3,4X,'M1=',I2,4X,'N1=',I2
     @,2X,'NT=',I5,2X,'ILIMIT=',I2,2X,'IEQ=',I2,2X, 'IFR=',I2,//,
     @  5X,'IDIA=',I2,2X,'IUF=',I2,2X,'INPR=',I4,2X,'KDIA=',I2,
     @  2X,'IGR=',I2,2X,'IROCK=',I2,2X,'IOBS=',I2,2X,'INPUT=',I2,
     @ 2X,'NTRIB=',I2,2X,'NBANK=',I3,2X,'IBED=',I2,//,5X,'NBED=',
     @ I2,2X,'MAXBED=',I2,2X,'MAXMA=',I2,2X,'NOBS=',I2,2X,'NX=',I2,
     @ 2X,'NTP=',I4,2X,'IBUG=',I2,2X,'ICHB=',I2,2X,'ICOFF=',I2,
     @ 2X,'IPLOT=',I2,2X,'IDREJ=',I2,2X,'NTY=',I3,//,5X,'IDSWS=',I2,
     @ ' IDELT=',I3,2X,'NRES=',I3)
```

```
56     FORMAT(//////,5X,'MA(I)')
58     FORMAT(12X,10I5)
68     FORMAT(25X,'SECTION...',I3,/)
74     FORMAT(/,20X,'TIME INTERVAL=',I4,2X,'DAYS',//)
88     FORMAT(///,28X,                      'SEDIMENT CONCENTRATION IS GIVEN
      *AT MOST UPSTREAM SECTION AS INPUT',/,28X,65('-'),//)
91     FORMAT(8F10.2)
92     FORMAT(8F10.7)
121    FORMAT(/,5X,'TF (F)')
122    FORMAT(/,5X,'VISC(SQ.FT./S *E05)',/)
125    FORMAT(/,5X,'TEMPF')
27     FORMAT(//,20X,'SECTION...',I3,//,7X,'STAGE',7X,'AREA',9X,
      *'HYD.RAD.',/)
29     FORMAT(//,5X,'STR=',F10.7,4X,'RMDS=',F8.1,//)
36     FORMAT(/,5X,'SSC(I,K)')
37     FORMAT(15X,F10.4,1X,F10.4,1X,F10.4,1X,F10.4,1X,F10.4,1X,F10.4,
      *1X,F10.4,1X,F10.4,1X,F10.4)
38     FORMAT(/,5X,'BB(I)')
39     FORMAT(12X,I5)
40     FORMAT(/,5X,'DW(I)')
41     FORMAT(/,5X,'CDF(I,K):',(T17,10F10.4))
42     FORMAT(/,5X,'QST(I)')
44     FORMAT(/,T2,'REACH LENGTHS:',(T17,10F10.0))
45     FORMAT(/,5X,'D50G(I)')
46     FORMAT(/,5X,'VAV(I)')
47     FORMAT(/,5X,'IDELT ')
48     FORMAT(/,5X,'POROSITY:',(T17,10F10.4))
49     FORMAT(/////,10X,'NO.OF SECTIONS=',I3,//,10X,'NO.OF SEGMENTS=',
      *I2,//,10X,'NO. OF SED.SIZE FRACTIONS=',I2,///)
50     FORMAT(/,5X,'SF(I)')
57     FORMAT(/,5X,'STAGE(N1)')
59     FORMAT(/////////////,25X,75('*'),///,27X,'WATER SURFACE PROFILE RE
      *MAINS THE SAME AS IN THE PREVIOUS TIME PERIOD',///,25X,75('*'),//)
61     FORMAT((T53,11F6.3))
62     FORMAT(/,5X,'D(K)')
64     FORMAT(/,5X,'VIS=',F10.7,2X, 'SQ.FT./SEC',/)
66     FORMAT(15X,F10.6,1X,F10.6,1X,F10.6,1X,F10.6,1X,F10.6,1X,F10.6,1X,
      *F10.6,1X,F10.6,1X,F10.6)
67     FORMAT(/////,10X,25('*'),4X,'WATER SURFACE PROFILE CALCULATIONS
      *AFTER',1X,I4,2X,'DAYS',4X,25('*'),///)
70     FORMAT('1',/ ,30X,'WATER SURFACE AND BED PROFILE AFTER',1X,I4,2X,
      *'DAYS',1X,'(',F6.2,1X,'YEARS )',/,30X,62('-'),/)
71     FORMAT( 1X,'SEC.',2X,'RM',3X,'B(FT.)',2X,'STAGE',2X,'Q(CFS.)'   ,
      *1X,'DEP(FT)',1X,
      *'V(FT/S)',1X,'EN.SLOPE',3X,'DZ(FT)',1X,'D50S(MM)',1X,'BED EL(FT)',
      *1X,'D50(MM)' ,2X,'ACF',3X,'ADEP(FT)',1X,'CM(PPM)',2X,'FF',2X,
      * 'DWS(FT)', /,1X,132(1H-))
72     FORMAT(1X,I3,1X,F5.1,2X,F5.0,2X,
      *                             F7.2,1X,F7.0,1X,F6.2,2X,F6.3,1X,F9.6,
      *1X,F7.3, 1X,F7.3,3X,F8.2,2X,F6.3,2X,F6.3,11X,F7.2,1X,F4.3,1X,F7.3)
75     FORMAT(101X,E12.4)
76     FORMAT(101X,E12.4,1X,'*')
79     FORMAT(/,1X,'PARTICLE SIZES:',(T17,10F10.4))
82     FORMAT(//// ,10X,'MODIFIED SECTION PROPERTIES AFTER', 1X,I4,1X,
      *'DAYS',/,10X,41('-'),/ )
84     FORMAT(3X,F10.3,3X,F10.3,3X,F10.3,3X,F10.3,3X,F10.3,3X,F8.3,3X,
      *F8.3,3X,F8.3,3X,F8.3)
413    FORMAT(/,5X,'SL1(I) (BED SLOPE*10000)',/)
```

```
1490  FORMAT(/,T20,'REACH',I3,' D50=',F7.3,' CDF,PDF:',(T51,12F6.3))
C
9000  RETURN
      END
C
C
C     -------------------------------------------------------
C
      SUBROUTINE INFLOW (Q,QTR,LOCTR,TEMPF,STAGE,QSUPS,QTRIB)
C
      DIMENSION Q(N),QTR(NTRIB),LOCTR(NTRIB),QTRIB(NTRIB),STAGE(N)
C
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
C
      IF (IT.EQ.1) ITDAT=0
C
C     READ NEW INFLOWS IF NEEDED
C
25    IF (ITIME.LE.ITDAT) GO TO 100
      DO 30 LT=1,NTRIB
            QTR(LT)=QTRIB(LT)
30    CONTINUE
      TEMPF=TFREAD
      STAGE(1)=YREAD
      QSUPS=QSREAD
      ITIMEP=ITDAT
      READ (5,1000,END=900) ITDAT, TFREAD,(QTRIB(LT),LT=1,NTRIB),YREAD,
     1 QSREAD
      WRITE(6,2002) ITDAT,TFREAD,QTRIB,YREAD,QSREAD
 2002 FORMAT(T5,'TIME-DEPENDENT DATA READ FOR ITDAT=',I5,':',F4.0,
     1       (T52,9F8.1),/)
      GO TO 25
1000  FORMAT (I4,F4.0,(T9,9F8.0))
C
C     INTERPOLATE BETWEEN VALUES AT PREVIOUS TIME STEP AND THOSE
C     MOST RECENTLY READ
C
100   FTIME=ITIME
      FINT=(FTIME-ITIMEP)/(ITDAT-ITIMEP)
      DO 125 LT=1,NTRIB
            QTR(LT)=QTR(LT)+FINT*(QTRIB(LT)-QTR(LT))
125   CONTINUE
      TEMPF=TEMPF+FINT*(TFREAD-TEMPF)
      STAGE(1)=STAGE(1)+FINT*(YREAD-STAGE(1))
      QSUPS=QSUPS+FINT*(QSREAD-QSUPS)
      ITIMEP=ITIME
C
C     COMPUTE WATER DISCHARGES AT ALL COMPUTATIONAL POINTS BY
C     ACCUMULATION OF TRIBUTARY INFLOWS
C
      Q(N)=QTR(1)
      LT=2
      LM=N
10    LM=LM-1
```

```
      IF (LM.EQ.0) GO TO 301
      Q(LM)=Q(LM+1)
      IF (LM.NE.LOCTR(LT)) GO TO 10
      Q(LM)=Q(LM)+QTR(LT)
      LT=LT+1
      GO TO 10
C
C      PRINT MAINSTEM DISCHARGES AT TRIBUTARY INFLOW POINTS
C
301   IF (IBUG.NE.0) WRITE (6,2000) IT,ITIME,NTRIM,
     1 (Q(LOCTR(K)),K=1,NTRIB)
2000  FORMAT (1X,'IT=',I4,' ITIME=',I4,' NTRIM=',I1,' FLOWS:',
     1(T35,12F8.0))
C
999   RETURN
900   WRITE (6,2001) ITIME, ITDAT
2001  FORMAT (/,20(1H*),' ERROR: ITIME=',I5,
     1' EXCEEDS LAST INFLOW DATA ITDAT=',I5)
      STOP
      END
C
C      ------------------------------------
        SUBROUTINE SEDBED (NBEL,THBED,PBED)
C      ------------------------------------
C
C      THIS SUBROUTINE READS ADDITIONAL SEDIMENT CHARACTERISTICS
C       IN CASE OF VERTICAL VARIATION OF ORIGINAL BED MATERIAL
C
C     NBEL(I)= NO. OF ELEVATIONS AT WHICH SED.SIZE DISTR. CHANGES
C                 AT REACH I
C     THBED(I)= THICKNESS OF HOMOGENEOUS SED.SIZE DIST. IN REACH I
C     PBED(I,K,L)= SED.SIZE DISTR.(IN FRACTION) ATREACH I,
C                       FRACTION K IN SEDIMENT LAYER L
C
C
      DIMENSION NBEL(NN),THBED(NN),PBED(NN,N1,MAXBED)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
C
      READ(5,10) (NBEL(I),I=1,NN)
      WRITE(6,15)
      WRITE(6,20) (NBEL(I),I=1,NN)
C
      READ(5,25) (THBED(I),I=1,NN)
      WRITE(6,30)
      WRITE(6,35) (THBED(I),I=1,NN)
C
      WRITE(6,40)
      DO 100 I=1,NN
      LL=NBEL(I)
      IF(LL.EQ.0) GO TO 100
      DO 100 L=1,LL
      READ(5,25) (PBED(I,K,L),K=1,N1)
      WRITE(6,35) (PBED(I,K,L),K=1,N1)
100   CONTINUE
C
10    FORMAT(12I5)
15    FORMAT(/,5X,'NBEL(I):',/)
```

```
20     FORMAT(10X,12I5)
25     FORMAT(6F10.3)
30     FORMAT(/,5X,'THBED(I) :',/)
35     FORMAT(10X,8F10.3)
40     FORMAT(/,5X,'PBED(I,K,L) :',/)
C
       RETURN
       END
C
C
C      ------------------------------------------------------------
        SUBROUTINE START(STAGE,Q,STAGE1,DMS,B,XAREA,MA,B1,R1,REACH,
      1                  SF,AREA)
C      ------------------------------------------------------------
C
C      THIS SUBROUTINE CALCULATES WATER SURFACE ELEVATIONS AT THE
C       DOWNSTREAM BOUNDARY ASSUMING UNIFORM FLOW
C
       DIMENSION STAGE(N),Q(N),STAGE1(N,MAXMA),DMS(N),B(N),
      @ XAREA(N),MA(N),B1(N,MAXMA),R1(N,MAXMA),REACH(NN),SF(N)
      @ ,AREA(N,MAXMA)
       COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
      1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
       COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
      1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
      2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
C
       I=1
       S1=STR
       A2=ALOG10(S1*1000.0)
       I1=MA(I)
       BTR=B1(I,I1)
       ITER=0
       D50F=DMS(I)
100    QU=Q(I)/BTR
       A1=ALOG10(QU/SQRT(1.65*32.2*D50F   **3))
       VFD=10.0**(-0.4812+0.3761*A1+0.3106*A2)
       VEL=VFD*SQRT(32.2*1.65*D50F   )
       ARE=Q(I)/VEL
       DO 150 L=1,I1
       IF(AREA(I,L).GT.ARE) GO TO 200
150    CONTINUE
200    C=(ARE-AREA(I,L-1))/(AREA(I,L)-AREA(I,L-1))
       STAGE(I)=STAGE1(I,L-1)+C*(STAGE1(I,L)-STAGE1(I,L-1))
       B(I)=B1(I,L-1)+C*(B1(I,L)-B1(I,L-1))
       BTR1=B(I)
       ERR=ABS(BTR1/BTR-1.0)
       ITER=ITER+1
       IF(ERR.LE.0.02) GO TO 500
       IF(ITER.GT.20) GO TO 500
       BTR=BTR1
       GO TO 100
500    CONTINUE
       RETURN
       END
C
C      ------------------------------------------------------------
        SUBROUTINE DACHAN (ICHBT,ICOFFT,ICHBL,ICOFFL,REACH,B1,
```

```
      @    AREA,NCHBL,NCOFFL,MA,R1)
C      ------------------------------------------------------
C
C      THIS SUBROUTINE READS AND COMPUTES THE EFFECTS OF CHANNEL-WIDTH
C         CHANGES AND  CHANNEL CUTOFF AS FUNCTION OF TIME
C
       DIMENSION ICHBT(NT3651),ICOFFT(NT3651),ICHBL(NT3651,N),
      @ ICOFFL(NT3651,NN),B1(N,MAXMA),REACH(NN),AREA(N,MAXMA),
      @ NCHBL(NT3651),NCOFFL(NT3651),MA(N),R1(N,MAXMA)
       COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
      1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
       COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
      1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
      2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
C
C      ICHBT(IT)=TIME INTERVALS IN WHICH CHANNEL WIDTHS ARE CHANGED
C      ICOFFT(IT)=TIME STEPS IN WHICH CUTOFFS ARE INCORPORATED
C      ICHBL(NI)=LOCATION (NODE NO.) OF CHANNEL-WIDTH CHANGES
C                     IN TIME INTERVAL IT
C      ICOFFL(NI)=LOCATION (REACH NO.) OF CUTOFFS IN TIME STEP IT
C      NCOFFT=TOTAL NO. OF TIME STEPS IN WHICH CUTOFFS ARE MADE
C      NCOFFL(I1)= TOTAL NO. OF CUTOFF-REACHES IN TIME STEP I1
C      NCHBT= TOTAL NO. OF TIME STEPS IN WHICH CHANNEL WIDTHS
C                ARE CHANGED
C      NCHBL(I1)= TOTAL NO. OF NODES OF CHANNEL-WIDTH CHANGES
C                    IN TIME STEP I1
C
C      READ PARAMETERS FOR CHANGING WIDTH
C
       IF(ICHB.EQ.0) GO TO 100
       WRITE(6,19)
       READ(5,10) NCHBT
       READ(5,10) (NCHBL(I1),I1=1,NCHBT)
       WRITE(6,12)NCHBT
       WRITE(6,14)
       WRITE(6,15) (NCHBL(I1),I1=1,NCHBT)
10     FORMAT(12I5)
12     FORMAT(//,10X,'NCHBT=',I3,//)
14     FORMAT(//,5X,'NCHBL(I1)',/)
15     FORMAT(15X,12I5)
C
       READ(5,10) (ICHBT(I1),I1=1,NCHBT)
       WRITE(6,16)
       WRITE(6,15) (ICHBT(I1),I1=1,NCHBT)
       WRITE(6,18)
       DO 50 I1=1,NCHBT
       L=NCHBL(I1)
       READ(5,10) (ICHBL(I1 ,I),I=1,L)
50     WRITE(6,15) (ICHBL(I1,I),I=1,L)
16     FORMAT(//,5X,'ICHBT(I1)',/)
18     FORMAT(//,5X,'ICHBL(I1,I)',/)
19     FORMAT(//,10X,'INPUT VALUES FOR CHANNEL-WIDTH CHANGES WITH ',
      @ 'TIME :',//)
100    CONTINUE
C
C      READ PARAMETERS FOR CHANNEL CUTOFF
C
       IF(ICOFF.EQ.0) GO TO 200
```

```
      WRITE(6,29)
      READ(5,10) NCOFFT
      READ(5,10) (NCOFFL(I1),I1=1,NCOFFT)
      WRITE(6,22) NCOFFT
      WRITE(6,24)
      WRITE(6,15) (NCOFFL(I1),I1=1,NCOFFT)
22    FORMAT(//,10X,'NCOFFT=',I3,//)
24    FORMAT(//,5X,'NCOFFL(I1)',/)
C
      READ(5,10) (ICOFFT(I1),I1=1,NCOFFT)
      WRITE(6,26)
      WRITE(6,15) (ICOFFT(I1),I1=1,NCOFFT)
      WRITE(6,28)
      DO 150 I1=1,NCOFFT
      L=NCOFFL(I1)
      READ(5,10) (ICOFFL(I1,I),I=1,L)
150   WRITE(6,15) (ICOFFL(I1,I),I=1,L)
26    FORMAT(//,5X,'ICOFFT(I1)',/)
28    FORMAT(//,5X,'ICOFFL(I1,I)',/)
29    FORMAT(//,10X,'INPUT VALUES FOR CHANNEL CUTOFF :',//)
200   CONTINUE
C
C     ADJUSTMENT FOR CHANNEL-WIDTH CHANGES
C
       RETURN
C     *************
       ENTRY CHANGE
C     *************
      IF(ICHB.EQ.0) GO TO 500
      ITEST=0
      DO 210 I1=1,NCHBT
      IT1=ICHBT(I1)
      IF(IT1.EQ.IT) ITEST=ITEST+1
      IF(IT1.EQ.IT) GO TO 215
210   CONTINUE
215   IF(ITEST.EQ.0) GO TO 500
      L=NCHBL(I1)
      DO 220 I2=1,L
      I=ICHBL(I1 ,I2)
      MM=MA(I)
      READ (5,30) (B1(I,MAI),MAI=1,MM)
      WRITE(6,32) IT1,I
      WRITE (6,35) (B1(I,MAI),MAI=1,MM)
      DO 220 MAI=1,MM
      AREA(I,MAI)=B1(I,MAI)*R1(I,MAI)
220   CONTINUE
30    FORMAT(8F10.1)
32    FORMAT(//,10X,60('*'),//,15X,'NEW CHANNEL WIDTHS (FT.),   ',
     @ 'IT=',I3,2X,'I=',I3,//,10X,60('*'),//)
35    FORMAT(10X,8F10.1)
500   CONTINUE
C
C     ADJUSTMENT FOR CHANNEL CUTOFF
C
      IF(ICOFF.EQ.0) GO TO 1000
      ITEST=0
      DO 310 I1=1,NCOFFT
      IT1=ICOFFT(I1)
```

```
      IF(IT1.EQ.IT) ITEST=ITEST+1
      IF(IT1.EQ.IT) GO TO 315
310   CONTINUE
315   IF(ITEST.EQ.0) GO TO 1000
      L=NCOFFL(I1)
      DO 320 I2=1,L
      I=ICOFFL(I1 ,I2)
      READ(5,30) REACH(I)
      WRITE(6,42) IT1,I
      WRITE(6,35) REACH(I)
320   CONTINUE
C
42    FORMAT(//,10X,65('*'),//,15X,'NEW REACH LENGTH (FT.) FOR',
     @ ' CUTOFF AT IT=',I3,2X,'REACH=',I3,//,10X,65('*'),//)
1000  CONTINUE
      RETURN
      END
C
C
C     ------------------------------------------------------------
       SUBROUTINE DADRED (IDRT,IDRL,NDRL,VDREJ,REACH,B,STAGE1,
     @  CDEP,AREA,R1,NBEL,THBED,PT,PTT,PBED,DARM,EL1,MA)
C     ------------------------------------------------------------
C
C     THIS SUBROUTINE READS AND COMPUTES THE EFFECT OF DREDGING
C
      DIMENSION IDRT(NT),IDRL(NT,N),NDRL(NT),VDREJ(N),REACH(NN),
     1 B(N),STAGE1(N,MAXMA),CDEP(N),DARM(N),AREA(N,MAXMA),
     2 R1(N,MAXMA),NBEL(NN),THBED(NN),PT(NN,N1),PTT(NN,N1),
     3 PBED(NN,N1,MAXBED),EL1(N),MA(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/DREJ/KDREJ
C
C     IDRT(IT)=TIME STEPS IN WHICH DREDGINGS ARE DONE
C     IDRL(NI)=LOCATION (REACH NO.) OF DREDGING IN TIME STEP IT
C     NDRT=TOTAL NO. OF TIME STEPS IN WHICH DREDGINGS ARE MADE
C     NDRL(IT)=TOTAL NO. OF REACHES OF DREDGING IN TIME STEP IT
C     VDREJ(I)=VOLUME OF DREDGING (CUBIC YARDS/DAY) IN REACH I
C
C     READ DREDGING PARAMETERS
C
      WRITE(6,49)
      READ(5,10) NDRT
      READ(5,10) (NDRL(I1),I1=1,NDRT)
      WRITE(6,52) NDRT
      WRITE(6,54)
      WRITE(6,15) (NDRL(I1),I1=1,NDRT)
10    FORMAT(12I5)
15    FORMAT(15X,12I5)
30    FORMAT(8F10.1)
49    FORMAT(//,10X,'INPUT VALUES FOR DREDGING :',//)
52    FORMAT(//,10X,'NDRT=',I3,//)
54    FORMAT(//,5X,'NDRL(I1)',/)
C
```

```
      READ(5,10) (IDRT(I1),I1=1,NDRT)
      WRITE(6,56)
      WRITE(6,15) (IDRT(I1),I1=1,NDRT)
      WRITE(6,58)
      DO 350 I1=1,NDRT
      L=NDRL(I1)
      READ(5,10) (IDRL(I1,I),I=1,L)
350   WRITE(6,15) (IDRL(I1,I),I=1,L)
56    FORMAT(//,5X,'IDRT(I1)',/)
58    FORMAT(//,5X,'IDRL(I1,I)',/)
400   CONTINUE
      RETURN
C     ************
      ENTRY DREDGE
C     ************
C
C     COMPUTES THE EFFECT OF DREDGING ON GEOMETRIC PROPERTIES
C
      ITEST=0
      DO 810 I1=1,NDRT
      IT1=IDRT(I1)
      IF(IT1.EQ.IT) ITEST=ITEST+1
      IF(IT1.EQ.IT) GO TO 815
810   CONTINUE
815   IF(ITEST.EQ.0) GO TO 1000
      KDREJ=1
      L=NDRL(I1)
      DO 890 I2=1,L
      I=IDRL(I1,I2)
      READ(5,30) VDREJ(I)
      WRITE(6,62) IT1,I,VDREJ(I)
      DDREJ=VDREJ(I)/(REACH(I)*(B(I)+B(I+1))/2.0)*27.0*IDELT
      CDEP(I)=CDEP(I)+DDREJ
      DARM(I)=0.0
      MM=MA(I)
      DO 820 L=1,MM
820   STAGE1(I,L)=STAGE1(I,L)-DDREJ
62    FORMAT(//,10X,70('*'),//,15X,'VOLUME OF DREDGING AT IT=',I4,
     1 2X,'I=',I3,2X,'IS:',F12.0,2X,'CU.YDS./DAY ',//,10X,70('*'),//)
C
C     COMPUTE THE EFFECT OF DREDGING ON BED-MATERIAL SIZE DISTR.
C
      IF(IBED.EQ.1.AND.NBEL(I).NE.0) GO TO 855
      BELIN=STAGE1(I,1)+CDEP(I)
      DO 852 K=1,N1
      IF(EL1(I).GE.STAGE1(I,1)) PT(I,K)=PTT(I,K)
852   CONTINUE
855   IF(IBED.EQ.0) GO TO 890
      IF(NBEL(I).EQ.0) GO TO 890
      NB=NBEL(I)
      DO 860 L=1,NB
      T1=BELIN-L*THBED(I)
      IF(T1.GT.STAGE1(I,1)) GO TO 865
860   CONTINUE
865   CONTINUE
      DO 890 K=1,N1
      IF(EL1(I).GE.STAGE1(I,1)) PT(I,K)=PBED(I,K,L)
      PTT(I,K)=PT(I,K)
```

```
890   CONTINUE
1000  CONTINUE
      RETURN
      END
C
C     ------------------------------------------
C     SUBROUTINE WATPRO
C     ------------------------------------------
C
C     THIS SUBROUTINE COMPUTES WATER SURFACE PROFILE, AVERAGE VELOCITY
C     AND FRICTION SLOPE BY STANDARD STEP METHOD
C
C
C     DEFINITION OF VARIABLES
C
C     SF(I)=ENERGY GRADIENT AT SECTION I
C     CONVF=CONVEYANCE FACTOR FOR WHOLE SECTION
C     CONVFL,CONVFR,CONVFM=CONVEYANCE FACTORS FOR LEFT,RIGHT AND
C              MAIN SUBSECTION, RESPECTIVELY
C     VEL=VELOCITY FOR THE WHOLE SECTION
C     VELCOF=VELOCITY COEFFICIENT
C     VH=VELOCITY HEAD
C     THEAD1=TOTAL HEAD,OBTAINED BY ADDING VELOCITY HEAD TO STAGE
C     THEAD2=TOTAL HEAD,OBTAINED BY ADDING FRICTION HEAD
C     DY=CORRECTION TO BE APPLIED TO THE ASSUMED STAGE VALUE
C     ITER=NO. OF ITERATIONS REQUIRED FOR BACKWATER COMPUTATIONS
C     OLDH2=TEMPORARY LOCATION FOR STORING THEAD2 OF PREVIOUS SECTION
C     CL,CR,CM,A1,A2=INTERMEDIATE VARIABLES FOR BACKWATER CALCULATIONS
C
C     -----------------------------------------------------------------
      SUBROUTINE DAWATP(REACH,STAGE,Q,STAGE1,D,XAREA,R,B,CTO,SF,FR,
     1    ACF,LOCTR,QTR,DMS,D50SLS)
C     -----------------------------------------------------------------
C
      DIMENSION REACH(NN),STAGE(N),Q(N),STAGE1(N,MAXMA),D(N1),
     1 XAREA(N),R(N),B(N),CTO(N),SF(N),FR(N),DMS(N),ACF(N),
     2 LOCTR(NTRIB),QTR(NTRIB),D50SLS(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/ARM1/IBLR,ISLR,FSLR
      VELCOF=1.0
      CON1=VELCOF/2.0/32.2
      ERR=0.05
      CON2=1./8./32.2
      CON3=32.2*1.65
      CON4=1./CON2
      RETURN
C     ************
      ENTRY WATPRO
C     ************
C
C     COMPUTATION STARTS AT THE CONTROL SECTION
C     (MOST DOWNSTREAM OR SECTION 1)
C
```

```
      I=1
C
C      TLTM ITERATION MANAGEMENT FOR SECTION 'I'
C
C
C      CALL SECPRO TO OBTAIN SECTION PROPERTIES
C
101   CALL SECPRO
      IF(IBUG.GT.0.AND.I.GT.1.AND.IPRINT.EQ.1) WRITE(6,55) I,ITER
C
C      CALL RESIS1 FOR TLTM CALCULATION
C
      CALL RESIS1
      FR(I)=FF
      XAREA(I)=R(I)*B(I)
      CONVF=SQRT(CON4*R(I)/FF)*XAREA(I)
      VEL=Q(I)/XAREA(I)
      VH=VEL*VEL*CON1
      THEAD1=STAGE(I)+VH
      IF (I.EQ.1) THEAD2=THEAD1
C
C     COMPUTATION STARTS AT THE NEXT SECTION
C
      IF(I.EQ.1) GO TO 135
      THEAD2=OLDH2 +(SF(I)+SF(I-1))*0.5*REACH(I-1)
      DEL= ABS(THEAD1-THEAD2)
135   IF (IBUG.GT.0.AND.IPRINT.EQ.1)
     1  WRITE(6,50) I,XAREA(I),R(I),STAGE(I),Q(I),
     * SF(I),VEL,THEAD1,THEAD2,ALPHA
      IF(I.EQ.1) GO TO 140
      T1=THEAD1-THEAD2
      XSIGN=SIGN(1.,T1)
      IF(DEL.LT.ERR) GO TO 140
      IF(ITER.EQ.30) GO TO 140
      A1=2.0*VH/R(I)
      A2=3.0*SF(I)*REACH(I-1)/(2.0*R(I))
      DY=(THEAD1-THEAD2)/(1.0-A1+A2)
      IF(IBUG.GT.0.AND.IPRINT.EQ.1)
     1 WRITE (6,20) I,DY,R(I),VEL,SF(I),FF,CPM
      STAGE(I)=STAGE(I)-DY
      ITER=ITER+1
      GO TO 101
140   IF (IBUG.GT.0.AND.IPRINT.EQ.2)
     1   WRITE(6,52) I,R(I),VEL,Q(I),SF(I),THEAD1,
     * THEAD2,FFCW,FU,CPPM,ITER
      IF(I.NE.1.AND.ITER.GT.30) CALL ERROR4(I,IT,ITIME,ITER,DEL)
C
C      BACKWATER ITERATION COMPLETED
C      DISTRIBUTE TOTAL SEDIMENT DISCHARGE AMONG SIZE FRACTIONS
C
      CALL TRASF
      I=I+1
C
C      INITIAL ESTIMATE OF STAGE OF NEXT U/S SECTION
C
      IF (I.LE.N) STAGE(I)=STAGE(I-1)+SF(I-1)*REACH(I-1)
      ITER=1
      OLDH2=THEAD2
```

```
      IF (I.LE.N) GO TO 101
20    FORMAT(5X,'I=',I3,2X,'DY=',F8.4,2X,'D=',F7.3,2X,'V=',F7.3,
     * 2X,'S=',F8.6,2X,'FF=',F7.4,2X,'CBAR=',F8.3)
50    FORMAT(/,5X,'I=',I3,2X,'A=',F10.2,2X,'R=',F5.2,2X,'H=',F9.4,2X,
     *'Q=',F9.2,2X,'SF=',F10.8,2X,'V=',F5.2,2X,'H1=',F9.4,2X,'H2=',
     *F9.4,2X,'ALPHA=',F6.3,/ )
52    FORMAT(5X,'I=',I4,2X,'D=',F6.3,2X,'V=',F6.3,2X,'Q=',F8.1,
     *  2X,'S=',F8.6,2X,'H1=',F8.3,2X,'H2=',F8.3,2X,'FCW=',F6.4,2X,
     *  'FU=',F6.4,2X,'CBAR=',F8.2,2X,'ITER=',I3,/)
55    FORMAT(/,15X,15('*'),2X,'I=',I3,2X,'ITERATION ....',I3,
     *  2X,15('*'),//)
C
C     RECALCULATING SEDIMENT DISCHARGE IN CASE OF TRIBUTARIES
C
      IF(NTRIB.EQ.1) GO TO 800
      DO 700 I2=2,NTRIB
      I4=LOCTR(I2)
      D50S=DMS(I4)
      IF(ISLR.EQ.1) D50S=D50SLS(I4)
      QMAIN=Q(I4)-QTR(I2)
      VL=QMAIN/(XAREA(I4))
      SLN=FR(I4)*VL**2.0*CON2/R(I4)
      A3=ALOG10(R(I4)/D50S    )
      A4=ALOG10(SLN)
      UST=SQRT(32.2*R(I4)*SLN)
      RS=UST*D50S   /VIS
      CALL SHIELD(RS,SHP)
      VAR1=SQRT(CON3*D50S    )
      USC=SQRT(SHP)*VAR1
      TEMP=AMAX1(UST-USC,0.001)
      A12=ALOG10(VL/ VAR1)
      A17=ALOG10(TEMP/VAR1)
      QS=10.0**(-2.2786+A12*2.9719+A12*A17*1.006+A3*A17*0.2989)
      CTO(I4)=QS*DMS(I4)*VAR1/(VL*R(I4))
      CTO(I4)=(1.0-FSLR*ALFA*ACF(I4))*CTO(I4)
700   CONTINUE
800   CONTINUE
      RETURN
      END
C
C        ---------------------------------------------
C             SUBROUTINE  RESIS1
C        ---------------------------------------------
C
C     THIS SUBROUTINE CALCULATES SEDIMENT DISCHARGE AND FRICTION FACTOR
C     USING THE TOTAL LOAD TRANSPORT MODEL (TLTM) DEVELOPED AT IIHR
C
C     -----------------------------------------------------
      SUBROUTINE DARESI(Q,DMS,D,XAREA,R,CTO,SF,ACF,CIN,D50SLS)
C     -----------------------------------------------------
C
      DIMENSION Q(N),DMS(N),D(N1),XAREA(N),R(N),CTO(N),SF(N),
     1 ACF(N),CIN(N),D50SLS(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
```

```
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/ARM/MIND,QMAX,IARMOR
      COMMON/ARM1/IBLR,ISLR,FSLR
      NAMELIST/RATS/IT,I,IT2,S1,V1,D1,F11,F1,VAR1,W,A12,A3,WLOG,
     1              DMSLOG,A4,T1P,S1P,UST,A6,A10,RS,USC,TEMP,A17,QS,
     2              A1,RIGHT,V1,V2,T1,T,TT,S1OLD
C
      ERRP=0.01
      ERRA=0.05
      ERRS=0.02
      CON3=32.2*1.65
      CON5=32.2/1000.0
      CON4=8.0*32.2
      CON9=STR*1000.0
      RETURN
C     ************
      ENTRY RESIS1
C     ************
C
      D50S=DMS(I)
      IF(ISLR.EQ.1) D50S=D50SLS(I)
      IT2=0
      S1=STR*1000.0
      IF(IT.GT.1) S1=SF(I)*1000.0
      V1=Q(I)/XAREA(I)
      D1=R(I)
      F11=36.0*VIS**2/(CON3*D50S  **3)
      F1=SQRT(2.0/3.0+F11)-SQRT(F11)
      VAR1=SQRT(CON3*D50S  )
      W   =F1*SQRT(1.65*32.2*D50S   )
      A12=ALOG10(V1/VAR1)
      A3   =ALOG10(D1/D50S   )
      WLOG=ALOG10(W)
      DMSLOG=ALOG10(D50S   )
C
C      BEGIN ITERATIVE SOLUTION
C
100   A4=ALOG10(S1)
      T1P=T1
      S1P=S1OLD
      UST=SQRT(D1*S1*CON5)
      A6=ALOG10(UST/W)
      A10=WLOG+DMSLOG-VISLOG
      RS=UST*D50S  /VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP)*VAR1
      TEMP=AMAX1(UST-USC,0.001)
      A17=ALOG10(TEMP/VAR1)
C
C      QS COMPUTED FROM EQ. 1, IIHR 250
C
      QS=10.0**(-2.2786+A12   *2.9719+A12   *A17   *1.0600+
     @  A3   *A17   *.2989)
 120  A1=ALOG10(QS)
C
C      U COMPUTED FROM EQ. 2, IIHR 250
C
212   RIGHT=10.0**(.9045+A1   *.1665+A1   *A6   *A10   *.0831+
```

```
     @ A6    *A10    *.2166+A3    *A4    *A6    *(-.0411))
C
C       ITERATION MANAGEMENT
C
214    V2=RIGHT*VAR1
       T1=V1-V2
       XSIGN=SIGN(1.0,T1)
       IF(IT2.EQ.0) X1=XSIGN
       IF(XSIGN.NE.X1) GO TO 150
       T=ABS(T1)
       TT=T/V1
       IF(T.LE.ERRA .OR.TT.LE.ERRP) GO TO 150
       IF (IT2.GT.60) GO TO 150
       S1=S1*(1.0+SIGN(ERRS,T1))
C
C       REGULA FALSI CORRECTION OF S1
C
       S1OLD=S1
C      IF(IT2.GT.0) S1=S1-T1*(S1-S1P)/(T1-T1P)
C      IF(IT2.EQ.0) S1=S1*(1.+0.3*SIGN(1.,T1))
C      IF(S1.LT.0.0) S1=AMAX1(S1,CON9)
       IT2=IT2+1
       IF(IBUG.EQ.0) GO TO 100
       IF(IT.EQ.1) GO TO 100
       IF(IPRINT.EQ.0) GO TO 100
       CBAR=CTO(I)*2.65E6
       IF(IT2.EQ.1) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
       IF(IT2.EQ.5) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
       IF(IT2.EQ.10) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
       IF(IT2.EQ.100) WRITE(6,15) IT2,V1,V2,S1,CBAR,QS
15     FORMAT(5X,'IT2=',I4,2X,'V1=',F6.2,2X,'V2=',F6.2,2X,'S1=',2X,
     *  E14.7,2X,'CBAR=',F9.2,2X,'QS=',E14.7)
       GO TO 100
C
C       ITERATION COMPLETED
C
 150   IF (IT2.LE.10) GO TO 152
C      CALL ERROR5(I,IT,ITIME,IT2,TT)
C      WRITE(6,RATS)
C      IF(IT2.GT.60) STOP
C
C       COMPUTE TLTM FRICTION FACTOR
C
 152   SF(I)=S1/1000.0
       FF=CON4*D1*S1/(1000.0*V1**2)
       FU=FF
 154   AA=0.0
       IC=0
       IF(IT.EQ.1) I8=N1-1
       IF(IT.GT.1) I8=MIND
       DO 153 IA=I8  ,N1
       IC=IC+1
 153   AA=AA+D(IA)
       DA=AA/FLOAT(IC)
       IF(IPRINT.EQ.1) WRITE(6,25) I,D1,V1,S1,FF,CPM
C
C       COMPUTE COLEBROOK-WHITE FRICTION FACTOR
C
```

```
      CRI=2.*ALOG10(2.0*D1/DA)+1.14
      IF(IBUG.EQ.1) WRITE(6,23) D(IA),DA,CRI,D1,S1,DMS(I)
23    FORMAT(5X,'D=',E14.7,2X,'DA=',E14.6, 2X,'CRI=',E14.7,2X,
     @ 'D1=',E14.6,2X,'S1=',E14.6,2X,'D50=',E14.6)
      FFCW=1.0/(CRI)**2
      IF(IPRINT.EQ.1) WRITE(6,22) FF,FFCW
C
C      COMPUTE COMPOSITE FRICTION FACTOR (EQ.5 IIHR 250)
C
      FF=(1.-FSLR*C21*ACF(I))*FF+C22*FSLR*ACF(I)*FFCW
      R(I)=D1
      SF(I)=FF*V1**2/(CON4*D1)
      S1=SF(I)*1000.0
C
C      UPDATE SEDIMENT DISCHARGE FOR COMPOSITE FRICTION FACTOR
C
156   A4=ALOG10(S1)
      UST=SQRT(32.2*D1   *S1  /1000.0)
      A6=ALOG10(UST/W)
      RS=UST*D50S  /VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP)*VAR1
      TEMP=AMAX1(0.001,UST-USC)
      A17=ALOG10(TEMP/VAR1)
      QS=10.0**(-2.2786+A12   *2.9719+A12   *A17   *1.0600+
     @  A3   *A17   *.2989)
165   CTO(I)=QS*SQRT(CON3*D50S  **3)/(V1*D1)
      IF (IT.EQ.1) CIN(I)=CTO(I)
      CTO(I)=(1.-FSLR*ALFA*ACF(I))*CTO(I)
155   CPPM=CTO(I)*2.65E6
      IF(IPRINT.EQ.1) WRITE(6,10) I,D1,V1,V2,SF(I),FF,CPPM,IT2,ACF(I)
10    FORMAT(//, 6X,'I=',I3,2X,'D=',F5.2,2X,'V1=',F5.2,2X,'V2=',F5.2,
     *2X,'SF=',F9.7,2X,'F=',F6.4,2X,'CBAR=',F9.2,2X,'IT=',I4,
     *2X,'ACF=',F9.7,/)
22    FORMAT(/,5X,'FF=',  F7.5,2X,'FFCW=',F7.5)
25    FORMAT(5X,'I=',I3,2X,'D1=',F7.3,2X,'V1=',F7.3,2X,'S1=',F8.6,
     *  2X,'FF=',F7.4,2X,'CBAR=',F8.3)
500   RETURN
      END
C
C         --------------------------------------
C                SUBROUTINE   TRASF
C         --------------------------------------
C
C         THIS SUBROUTINE CALCULATES SEDIMENT DISCHARGE BY SIZE
C         FRACTION BY IIHR METHOD (EQ.20 IIHR 250)
C
C      --------------------------------------------------
      SUBROUTINE DATRAS(D50,D,PT,SSC,R,CTO,SF,PQS,PDN,PAC)
C      --------------------------------------------------
C
      DIMENSION D50(NN),D(N1),PT(NN, N1),SSC(N, N1),R(N),CTO(N),
     1 SF(N),PQS(N, N1),PDN(N, N1),PAC(N,N1)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
```

```
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/BANK/IBSED,QMIN,IUPS
      COMMON/ARM1/IBLR,ISLR,FSLR
C
      RETURN
C
      ENTRY TRASF
C
C
      IF(I.EQ.N) GO TO 100
      SS=0
      X=0.0316*(R(I)/D50(I))**0.50
      DO 160  K=1,N1
      IF(IT.EQ.1) PAC(I,K)=PT(I, K)
      UST=SQRT(32.2*R(I)*SF(I))
      RS=UST*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D(K))
      PROB=1.00
      IF(UST.LE.USC) PROB=0.00
      IF(IBLR.EQ.0)SS=SS+PT(I, K)*((D50(I)/D(K))**X)*PROB
      IF(IBLR.EQ.1)SS=SS+PAC(I,K)*((D50(I)/D(K))**X)*PROB
160   CONTINUE
      N2=N1-1
      DO 200 K=1,N1
      UST=SQRT(32.2*R(I)*SF(I))
      RS=UST*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D(K))
      PROB=1.00
      IF(UST.LE.USC) PROB=0.00
      PSI=0.0
      IF(SS.NE.0.0) PSI=PT(I, K)*((D50(I)/D(K))**X)/SS*PROB
      IF(SS.NE.0.AND.IBLR.EQ.1) PSI=PAC(I,K)*((D50(I)/D(K))**X)
     @  *PROB/SS
      PQS(I, K)=PSI
      SSC(I, K)=CTO(I)*PSI
      IF(IBUG.EQ.1) WRITE(6,37) I, K,SSC(I, K)
37    FORMAT(/,5X,'SSC(',I2,',',I1,',',I2,')=',E14.6)
200   CONTINUE
      S2=0
      DO 250 K=1,N1
250   S2=S2+PQS(I, K)*(D(K)/D50(I))**X
      DO 260 K=1,N1
C     PDN(I, K)=PQS(I, K)*(D(K)/D50(I))**X/S2
      IF(IBLR.EQ.0)PDN(I, K)=PT(I, K)
      IF(IBLR.EQ.1) PDN(I, K)=PAC(I,K)
260   CONTINUE
100   IF(INDSS.EQ.1.AND.IUPS.EQ.0) CTO(N)=CPPMUP/(2.65*1000000.0)
      RETURN
      END
C
C
C     -----------------------------------------------
C     SUBROUTINE SECPRO
C     -----------------------------------------------
C
C
```

```
C     THIS SUBROUTINE COMPUTES CROSS SECTIONAL AREA,HYD.RADIUS AND WATER
C     SURFACE WIDTH AT SECTION I FOR A PARTICULAR ELEVATION
C
C     -------------------------------------------------------
      SUBROUTINE DASECP(STAGE,MA,STAGE1,B1,R1,AREA,XAREA,R,B)
C     -------------------------------------------------------
C
      DIMENSION STAGE(N),MA(N),STAGE1(N,MAXMA),B1(N,MAXMA),
     1 R1(N,MAXMA),AREA(N,MAXMA),XAREA(N),R(N),B(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,I,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF,VISLOG
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
C
      RETURN
C     ************
      ENTRY SECPRO
C     ************
C
C     DEFINITION OF VARIABLES
C
C     XAREA(I)=CROSS SECTION AREA OF THE WHOLE SECTION AT SECTION I
C     R(I)=HYD. RADIUS OF THE WHOLE SECTION AT SECTION I
C     B(I)=WATER SURFACE WIDTH OF WHOLE SECTION AT SECTION I
C
C     XAREAL(I),XAREAR(I),XAREAM(I)=CROSS SECTION AREAS AT SECTION I OF
C            LEFT,RIGHT AND MAIN SUBSECTION,RESPECTIVELY
C     RL(I),RR(I),RM(I)=HYD. RADIUS AT SECTION I FOR LEFT,RIGHT AND MAIN
C                       SUBSECTION,RESPECTIVELY
C     BBL(I),BBR(I),BBM(I)= WATER SURFACE WIDTH AT SECTION I FOR LEFT,
C                           RIGHT AND MAIN SUBSECTION, RESPECTIVELY
C
      MM=MA(I)
      IF(STAGE(I).LE.STAGE1(I,1).OR.STAGE(I).GE.STAGE1(I,MM))
     @  STAGE(I)=STAGE1(I,1)+R(I)
      A=STAGE(I)
      IF(A.LE.STAGE1(I,1)) GO TO 200
      DO 150 L=1,MM
      D=STAGE1(I,L)
      IF(IBUG.EQ.1) WRITE(6,10) A,D,MM,L
10    FORMAT(10X,'A=',F10.2,2X,'D=',F10.2,2X,'MM=',I2,2X,'L=',I2)
      IF(D.GT.A) GO TO 170
150   CONTINUE
      L=MM
170   C=(A-STAGE1(I,L-1))/(STAGE1(I,L)-STAGE1(I,L-1))
      XAREA (I)=AREA (I,L-1)+(AREA (I,L)-AREA (I,L-1))*C
      R(I)=R1(I,L-1)+(R1(I,L)-R1(I,L-1))*C
      B(I)=B1(I,L-1)+(B1(I,L)-B1(I,L-1))*C
      IF(IBUG.EQ.1) WRITE(6,30) I,A,STAGE1(I,1),XAREA(I),R(I),B(I)
      IF(A.GT.STAGE1(I,MM)) WRITE(6,20) I,IT,A,D
      GO TO 300
200   WRITE(6,25) I,IT,A,D
20    FORMAT( 5X, 8('*'),2X,'W.S. ELEV. EXCEEDS TOP ELEV. OF ',
     @    'X-SECTION AT I=',I3,2X,'IT=',I4,2X,'WSE=',F8.2,2X,
     @    'D=',F8.2,2X,8('*'))
25    FORMAT( 5X, 8('*'),2X,'W.S. ELEV. BELOW BOTTOM OF ',
```

```
     @    'X-SECTION AT I=',I3,2X,'IT=',I4,2X,'WSE=',F8.2,2X,
     @    'D=',F8.2,2X,8('*'))
30    FORMAT(5X,'I=',I4,2X,'WSE=',F9.3,2X,'BEL=',F8.3,2X,'A=',
     @  F8.1,2X,'R=',F8.3,2X,'B=',F8.3)
300   RETURN
      END
C
C
C     ---------------------------------------------------
C     SUBROUTINE SLOAD
C     ---------------------------------------------------
C
C     THIS SUBROUTINE APPLIES SEDIMENT CONTINUITY EQUATION AND
C     CALCULATES DEPTHS OF DEGR./AGGR.
C
C     DEFINITION OF VARIABLES
C
C
C     SSC(I,K)= SUSPENDED SEDIMENT CONCENTRATION AT SECTION I ,
C               SEGMENT J, SED. FRACTION K
C     BB(I)=WIDTH OF SECTION I,SEGMENT J
C     W(K)= FALL VELOCITY OF SEDIMENT PARTICLE OF FRACTION K
C     ERVEL(I,K)=EROSION VELOCITY AT SECTION I, SEG.J,SED.FR. K
C     CB(I,K)= SEDIMENT CONCENTRATION IN BED LAYER AT SECTION I,
C                SEGMENT J, SED. FRACTION K
C     EZ(I,K )= TRANSEVERSE DIFFUSION COEFFICIENT FOR SEDIMENT IN
C                 SECTION I, SEGMENT J, FOR SED. FR. K
C     N= NO. OF SECTIONS(IN LONGITUDINAL DIRECTION)
C     NN=NO. OF REACHES=N-1
C     M1= NO. OF SEGMENTS
C     N1=NO. OF SEDIMENT SIZE FRACTIONS
C     REACH(I)= LENGTH OF REACH BETWEEN SECTIONS I AND I+1
C     MANG(I)= MANNING'S COEFFICIENT AT SECTION I,SEGMENT J
C     VAV(I)= AVERAGE VELOCITY AT SECTION I,SEGMENT J
C     DELT=TIME INTERVAL(DAYS)
C     P(K)= POROSITY FOR SEDIMENT FRACTION K
C     SI=PARAMETER FOR TRANSEVERSE SEDIMENT TRANSFER
C     CC,CD,TEST=INTERMEDIATE VARIABLES FOR SUSP. SEDIMENT CALCULATIONS
C     KA(I,K)=INDEX VARIABLE TO INDICATE WHETHER LIMITING SCOURING
C        DEPTH IS REACHED AT SECTION I,SEGMENT J, SED.FR. K(=0,LIMITING
C               DEPTH NOT REACHED; =1, LIMITING DEPTH REACHED )
C
C      NOTE: RA AND BB ARE PSEUDONYMS FOR R AND B
C
C     ---------------------------------------------------
      SUBROUTINE DASLOA(REACH,P,D,PT,PTT,SSC,CTO,SF,ACF,RA,BB,
     1 DW,DELDS,TDELD,CDEP,KA,VOLOUT,DELT,PQS,PDN,CDEP1,
     2 TB,ACF1,LOCTR,QSTR,PTRIB,TDELTR,LOCBER,BEROS,PBANK,Q,PTA,
     3    D50,THBED,NBEL,STAGE1,PBED,DARM,EL1,VAV,QSDP)
C     ---------------------------------------------------
C
      DIMENSION REACH(NN),P(N1),D(N1),PT(NN,N1),PTT(NN,N1),
     1 SSC(N,N1),CTO(N),SF(N),ACF(N),RA(N),BB(N),
     2 DW(N),DELDS(N,N1),TDELD(N,N1),CDEP(N),
     3 KA(N,N1),VOLOUT(N),DELT(N,N1),PQS(N,N1),
     4 PDN(N,N1),CDEP1(N),TB(N,N1),ACF1(N),QSTR(NTRIB),
     5 PTRIB(NTRIB,N1),TDELTR(NTRIB,N1),LOCTR(NTRIB),
     6 LOCBER(NBANK),BEROS(NBANK),PBANK(NBANK,N1),Q(N),
```

```
     7 PTA(NN,N1),      D50(NN),THBED(NN),NBEL(NN),STAGE1(N,MAXMA),
     8 PBED(NN,N1,MAXBED),DARM(N),EL1(N),VAV(N),QSDP(NN)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/SLOHYS/I,K
      COMMCN/BANK/IBSED,QMIN,IUPS
      COMMON/ARM/MIND,QMAX,IARMOR
C
      CON3=1.65*32.2
      THETA=1.0
      THETA1=1.0-THETA
      RETURN
C     ***********
      ENTRY SLOAD
C     ***********
C
C      LOOP ON REACHES, U/S TO D/S
C
603   DO 1000 I1=2,N
      I=N+1-I1
      I5=I
      I6=I+1
      QSTU=Q(I+1)/((BB(I)+BB(I+1))*0.5)
      DELCTO=CTO(I+1)-CTO(I)
      IF(I.EQ.N-1) DELCTO=0.0-CTO(I)
      QSD=THETA*DELCTO+THETA1*QSDP(I)
      QSDP(I)=DELCTO
C
C      LOOP ON SEDIMENT SIZE FRACTIONS FOR EACH REACH
C
604   DO 800 K=1,N1
      VAR1=SQRT(CON3*D(K))
599   KA(I,K)=0
      WFAC=1.00
C
C      COMPUTATION OF TRANSPORT CAPACITY BY SIZE FRACTION
C       IN EACH REACH
C
      DO 200 I2=I5,I6
      UST=SQRT(32.2*RA(I2)*SF(I2))
      RS=UST*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP)*VAR1
      F11=36.0*VIS**2/(CON3*D(K)**3)
      F1=SQRT(2.0/3.0+F11)-SQRT(F11)
      WI  =F1*VAR1
      A3=ALOG10(RA(I2)/D(K))
      A4=ALOG10(SF(I2)*1000.0)
      A12=ALOG10(VAV(I2)/VAR1)
      TEMP=AMAX1(UST-USC,0.001)
      A17=ALOG10(TEMP/VAR1)
      QSK=10.0**(-2.2786+A12*2.9719+A12*A17*1.0600+A3*A17*0.2989)
      IF(INDSS.EQ.1.AND.I2.EQ.N) QSK=CPPMUP/2.65E6
     @  *PTRIB(1,K)
```

```
      IF(I2.EQ.I5) QSIK=QSK
 200  CONTINUE
C      QSK= U/S LOAD FRACTION K
C      QSIK= D/S LOAD FRACTION K
C      QSD= GLOBAL DEFICIT, REACH I ( +VE FOR AGGR. )
C      WFAC= 1 FOR GLOBAL DEGR. ,K DEGR
C      WFAC= 0 FOR OPPOSITE GLOBAL -K TREND
C      0<WFAC<1 FOR GLOBAL AGGR. , K DEGR
C
      IF(QSD.GT.0.0) WFAC=1.00-QSIK/QSK
      IF(QSD.GT.0.0.AND.WFAC.LT.0.0) WFAC=0.0
      IF(QSD.LT.0.0.AND.QSIK.LT.QSK) WFAC=0.0
      IF(ABS(QSD).LE.0.377E-6) WFAC=0
C
C      COMPUTATION OF DEGRADATION OR DEPOSITION IN
C      REACH I FOR FRACTION K , ADJUSTED FOR INCONSISTENCY
C      WITH GLOBAL TREND USING WFAC
C
      IF(QSD.LE.0.0)DELDS(I,K)=QSD*PQS(I,K)*QSTU/((1.-P(K))*REACH(I))
     1*IDELT*86400.0*WFAC
      IF(QSD.GT.0.0 ) DELDS(I,K)=QSD*PDN(I,K)*QSTU/((1.0-P(K))
     *  *REACH(I))*IDELT*86400.0*WFAC
 520  TDELD(I,K)=-DELDS(I,K)
C
C     ADUSTMENT FOR TRIBUTARY SEDIMENT INFLOWS
C
      DO 700 I2=1,NTRIB
      I4=LOCTR(I2)-1
      IF(I4.NE.I) GO TO 700
      IF(INDSS.EQ.0.AND.I2.EQ.1) QSTR(I2)=CTO(I)*Q(N)
      TDELTR(I2,K)=QSTR(I2)*IDELT*86400.0/((BB(I4)+BB(I4+1))
     1 /2.0*REACH(I4))*PTRIB(I2,K)/(1.0-P(K))
      TDELD(I4,K)=TDELD(I4,K)-TDELTR(I2,K)
 700  CONTINUE
C
C     ADJUSTMENT FOR BANK EROSION
C
      IF(NBANK.EQ.0) GO TO 800
      WF=0.0
      IF(Q(I).GT.QMIN) WF=1.00
      DO 725 I3=1,NBANK
      I4=LOCBER(I3)
      IF(I4.NE.I) GO TO 725
      EROS=BEROS(I3)*IDELT*REACH(I4)/5280.0/(1.0-P(K))/((BB(I4)
     1 +BB(I4+1))*0.5*REACH(I4))*WF
      IF(IBSED.EQ.0) PBANK(I3,K)=PTT(I4,K)
      TDELD(I4,K)=TDELD(I4,K)-EROS*PBANK(I3,K)
 725  CONTINUE
C
 800  CONTINUE
C
C     CHECK CONTINUITY IN CASE OF TRIBUTARIES OR BANK EROSION
C
      IF(NTRIB.EQ.1.AND.NBANK.EQ.0) GO TO 790
      IF(QSD.GE.0.0) GO TO 790
      DO 740 I2=1,NTRIB
      I3=LOCTR(I2)-1
      IF(I3.EQ.I) GO TO 746
```

```
740   CONTINUE
742   DO 745 I2=1,NBANK
      I3=LOCBER(I2)
      IF(I3.EQ.I) GO TO 746
745   CONTINUE
      GO TO 790
746   QSDI=0.
      DO 747 L=1,N1
747   QSDI=QSDI+TDELD(I,L)
      QSDO=QSDI
      DO 765 L=1,N1
      IF(TDELD(I,L).GE.0.0) GO TO 765
      IF(PQS(I,L).NE.0.0) GO TO 765
      I8=MIND
      IF(IT.EQ.1) I8=N1-1
      IF(L.GE.I8  ) GO TO 765
      QSDI=QSDI-ABS(TDELD(I,L))
      TDELD(I,L)=0.0
765   CONTINUE
      DO 775 L=1,N1
      IF(TDELD(I,L).NE.0.0) TDELD(I,L)=TDELD(I,L)+
     @   (QSDI-QSDO)*PQS(I,L)
775   CONTINUE
790   CONTINUE
C
C      CALL HYSORT TO UPDATE MIXED LAYER SIZE
C      DISTRIBUTION FOR REACH I
C
      CALL HYSORT
C
C      COMPUTE TOTAL DEGRADATION IN REACH I
C
825   TOTAL=0
      II=0
      III=0
      DO 550 K=1,N1
550   TOTAL=TOTAL+TDELD(I,K)
      IF(ABS(TOTAL).LE.0.001 ) TOTAL=0.0
      AB=TOTAL/DW(I)
      IF(AB.GT..08) II=II+1
      IF(AB.GT..01) III=III+1
      IF(IT.EQ.1) GO TO 570
      CDEP(I)=CDEP(I)+TOTAL
      DARM(I)=DARM(I)+TOTAL
      GO TO 571
570   CDEP(I)=TOTAL
      DARM(I)=TOTAL
C
C      CALL ARMOR TO UPDATE ARMORING FACTOR FOR REACH I
C
 571  CALL ARMOR
900   CONTINUE
1000  CONTINUE
C
C     CHECKING CRITERIA FOR RECOMPUTING BACKWATER PROFILE
C
      IF(IT.EQ.1) GO TO 1001
      IF(IFLAG.EQ.0) GO TO 1004
```

```
1001  DO 1002 I=1,NN
1002  CDEP1(I)=CDEP(I)
1004  IF(II.EQ.1.OR.III.GT.ILIMIT) GO TO 1015
      IFLAG=0
      LL=0
      DO 1010 I=1,NN
      A4=CDEP(I)-CDEP1(I)
      A4=ABS(A4)/DW(I)
      IF(A4.GT..01 ) LL=LL+1
      IF(A4.GT..08 ) IFLAG=1
1010  CONTINUE
      IF(LL.GT.ILIMIT) IFLAG=1
      IF(IFLAG.EQ.0) GO TO 1005
1015  IFLAG=1
C
C     PRINT OUT OF RESULTS
C
1005  IF(IBUG.EQ.0.OR.IPRINT.EQ.0) GO TO 1006
      WRITE(6,99) IFLAG
      WRITE(6,98) ITIME
1006  DO 500 I1=2,N
      I=N+1-I1
      IF(IBUG.EQ.1) WRITE(6,50) I,J
      DO 500 K=1,N1
      PCENT= PT(I,K) *100.0
      IF(DELT(I,K).EQ.0) DELT(I,K)=900.0
500   IF(ISED.EQ.1.AND.IBUG.EQ.1) WRITE(6,65) K,TDELD(I,K),PCENT
501   CONTINUE
      IF(IBUG.EQ.0.OR.IPRINT.EQ.0) GO TO 9999
      N4=N-1
      DO 502 I4=1,N4
      WRITE(6,86) I4,(TDELD(I4,K),K=1,N1)
      WRITE(6,87) I4,(PT(I4,K),K=1,N1)
      WRITE(6,88) I4,(PQS(I4,K),K=1,N1)
      WRITE(6,89) I4,(DELT(I4,K),K=1,N1)
502   WRITE(6,95)
86    FORMAT(10X,'I=',I3,3X,'DEGR/AGGR.',2X,9F9.5 )
87    FORMAT(10X,'I=',I3,3X,'   S.D.(BM)',2X,9F9.5 )
88    FORMAT(10X,'I=',I3,3X,'   S.D.(QS)',2X,9F9.5 )
89    FORMAT(10X,'I=',I3,3X,'DELT(DAYS)',2X,9F9.2 )
50    FORMAT(///,10X,'REACH....',I3,5X,'SEGMENT..',I2,/,10X,28('-'),//,
     *10X,'SED.FRACTION',15X,'CHANGE IN BED ELEVATION(FT.)'//32X,'BED LO
     *AD',11X,'SUSP. LOAD',12X,'TOTAL',10X,'PERCENTAGE',/)
65    FORMAT(15X,I2,50X,E14.6,8X,F8.4)
98    FORMAT(/////,10X,30('*'),4X,'SEDIMENT CALCULATIONS AFTER',1X,
     *I4,2X,'DAYS',4X,30('*'),///)
96    FORMAT(//,10X,'A4=',F8.4)
99    FORMAT(////,10X,'IFLAG=',I2)
95    FORMAT(/    )
9999  RETURN
      END
C
C
C     -----------------------------------------------------------
        SUBROUTINE DAARMO (ACF,ACF1,PT,D,P,CDEP,PTT,VOLOUT,BB,SF,
     @      D50,THBED,PTA,NBEL,STAGE1,PBED,Q,RA,DARM,EL1,ARM,PAC,
     &      TDELD)
C     -----------------------------------------------------------
```

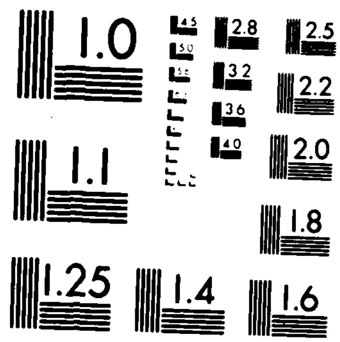
```
C
C     THIS SUBROUTINE CALCULATES ARMORING OF BED SURFACE
C
C     IBLR= INDEX VARIABLE FOR INCLUDING BED LAYER IN SEDIMENT
C             CALCULATIONS;  0 IF BED LAYER IS NOT INCLUDED (IMPLYING
C             USE OF ARMORING PROCEDURE); 1 IF BED LAYER IS
C             CONSIDERED (ARMORING PROCEDURE NOT USED)
C     ISLR= INDEX VARIABLE FOR SURFACE-LAYER D50 CALCULATIONS; 0 IF
C             SURFACE-LAYER D50 NOT USED; 1 IF USED IN SEDIMENT-DISC.
C             CALCULATIONS
C     IARMOR=INDEX VARIABLE TO SPECIFY OR DETERMINE ARMORING
C                SEDIMENT SIZE; IARMOR=0, SPECIFY; =1 FOR
C                DETERMINING INTERNALLY
C     MIND= FRACTION NUMBER FOR THE MINIMUM SEDIMENT SIZE WHICH
C           (AND COARSER FRACTIONS) FORM ARMOR COAT
C     QMAX=MAXIMUM WATER DISCHARGE(CFS.) FOR DETERMINING NON-MOVING
C              ARMORING FRACTIONS
C     IQMAX=INDEX VARIABLE FOR SPECIFYING WATER DISCHARGE FOR ARMORING
C              CALCULATIONS; IQMAX=0 FOR USING SPECIFIED CONSTANT
C              QMAX IN EACH TIME STEP AND REACH; =1 FOR USING WATER
C              DISCHARGE FROM SPECIFIED HYDROGRAPH
C     KARM=INDEX VARIABLE FOR MODIFYING THE ARMORING COEFFICIENT
C           (CARM); 0 FOR USING SPECIFIED VALUES; 1 FOR MODIFYING
C           CARM USING GESSLER'S RELATION; 2 FOR USING BED-LOAD
C           METHOD; 3 FOR USING BOTH GESSLER'S AND BED-LOAD METHODS ;
C           4 FOR USING DUNE-HEIGHT METHOD ; 5 FOR USING BOTH
C           GESSLER'S AND DUNE-HEIGHT METHODS
C     IACF=INDEX VARIABLE FOR SPECIFYING INITIAL ARMORING; 0 FOR NO
C           INITIAL ARMORED AREA; 1 IF ARMORED COAT (PARTIAL OR FULL)
C           EXISTS AT THE BEGINNING
C
      DIMENSION P(N1),D(N1),PT(NN, N1),PTT(NN, N1),CDEP(N),
     1 VOLOUT(N),ACF(N),ACF1(N),BB(N),SF(N),D50(NN),THBED(NN),
     2 PTA(NN, N1),NBEL(NN),STAGE1(N,MAXMA),PBED(NN  , N1,MAXBED)
      DIMENSION Q(N),RA(N),DARM(N),EL1(N),ARM(N,N1),PAC(N,N1)
      DIMENSION TDELD(N, N1)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ, NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/SLOHYS/I, L7
      COMMON/ARM/MIND,QMAX,IARMOR,IQMAX
      COMMON/DREJ/KDREJ
      COMMON/ARM1/IBLR,ISLR,FSLR
C
C     READ INDEX VAR. FOR USE OF BED LAYER
C
      READ(5,1000) IBLR,ISLR
      WRITE(6,1002) IBLR,ISLR
      FSLR=1.0
      IF(ISLR.EQ.1) FSLR=0.0
      IF(IBLR.EQ.0) WRITE(6,41)
      IF(IBLR.EQ.1) WRITE(6,42)
41    FORMAT(//,10X,'BED LAYER IS NOT CONSIDERED (ARMORING PROCEDURE',
     1 ' USED)',/,10X,53('-'),/)
42    FORMAT(//,10X,'BED LAYER IS CONSIDERED (ARMORING PROCEDURE NOT',
     1 ' USED)',/,10X,53('-'),/)
```

```
1002  FORMAT(/,10X,'IBLR=',I2,4X,'ISLR=',I2)
      IF(IBLR.EQ.1) GO TO 4000
C
C      READ ARMORING INPUT PARAMETERS DURING PREPARATORY PHASE
C      OF RUN.
C
      READ(5,1000)  IARMOR,MIND,QMAX,IQMAX,IACF,KARM,C1
 1000 FORMAT(2I5,F10.0,3I5,F10.4)
      DARMOR=0.
      IF(IARMOR.EQ.0) DARMOR=D(MIND)*304.8
      WRITE(6,43) IARMOR,MIND,QMAX,IQMAX,DARMOR,IACF,KARM,C1
   43 FORMAT(/,T10,'BED ARMORING PARAMETERS: IARMOR=',I2,' MIND=',
     1       I3,' QMAX=',F10.2,' IQMAX=',I2,' DARMOR=',F10.3,
     2 2X,'IACF=',I2,2X,'KARM=',I2,2X,'C1=',F6.3,/,
     3       T10,24(1H-))
C
      IF(IACF.EQ.1) GO TO 2000
      DO 1010 I1=1,NN
      DO 1010 K1=1,N1
      ARM(I1,K1)=0.0
1010  CONTINUE
      GO TO 2500
2000  DO 2010 I1=1,NN
      READ(5,101) (ARM(I1,K1),K1=1,N1)
      WRITE(6,110)
      WRITE(6,120)(ARM(I1,K1),K1=1,N1)
2010  CONTINUE
101   FORMAT(6F10.6)
110   FORMAT(/,T10,'INITIAL ARMOR-COVERED AREA (FRACTION) :',/)
120   FORMAT(T15,10F8.4)
2500  DO 3500 I1=1,NN
      ACF(I1)=0.0
      DO 3000 K1=1,N1
      ACF(I1)=ACF(I1)+ARM(I1,K1)
3000  CONTINUE
3500  CONTINUE
4000  IF(IBLR.EQ.0) GO TO 5000
      DO 4050 I1=1,NN
4050  ACF(I1)=0.0
5000  RETURN
C*************************************
      ENTRY ARMOR
C*************************************
C
      IF(IBLR.EQ.1) GO TO 800
C
105   S1=(SF(I)+SF(I+1))/2.0
100   IF(IARMOR.EQ.0) GO TO 200
C
C     COMPUTE THE ARMORING SEDIMENT SIZE
C
      IF(IQMAX.EQ.1) GO TO 170
      A1=QMAX/((BB(I)+BB(I+1))*0.50)/((32.2*1.65*D50(I)**3)
     1 **0.50)
      A1=ALOG10(A1)
      A2=ALOG10(S1    *1000.0)
      VFD=10.0**(-0.4812+0.37610*A1+0.31060*A2)
      VEL=VFD*SQRT(32.2*1.65*D50(I))
```

AD-A147 413 BED ARMORING PROCEDURES IN IALLUVIAL AND APPLICATION TO THE MISSOURI RIVER(U) IOWA INST OF HYDRAULIC RESEARCH IOWA CITY M F KARIM ET AL. DEC 83 IIHR-269 3/3

UNCLASSIFIED DACW45-79-C-0020 F/G 8/8 NL

END


1.0
2.8
2.5
3.2
2.2
3.6
4.0
1.1
2.0
1.8
1.25
1.4
1.6

```
      DEP=QMAX/(BB(I)+BB(I+1))*0.50/VEL
      USTAR=SQRT(32.2*DEP*S1)
170   IF(IQMAX.EQ.1) USTAR=SQRT(32.2*(RA(I)+RA(I+1))/2.0*S1)
      DO 180 K=1,N1
      RS=USTAR*D(K)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D(K))
      IF(USC.GT.USTAR) GO TO 185
180   CONTINUE
185   MIND=K
      IF(USC.LT.USTAR) MIND=N1+1
      IF(MIND.LE.N1) DARMOR=D(MIND)*304.8
      IF(MIND.GT.N1) DARMOR=2.0*D(N1)*304.8
      IF(IBUG.EQ.1) WRITE(6,16) MIND,DARMOR ,IT,I
16    FORMAT(   10X,'MIND=',I2,3X,'DMIN=',F8.3,'MM.',3X,'IT=',I4,4X,
     @ 'I=',I3   )
200   CONTINUE
C
C     ADJUSTING SIZE DISTRIBUTION OF ARMORING FRACTIONS IN CASE OF
C        VERTICAL VARIATION OF BED MATERIAL
C
      BEDEL=STAGE1(I,1)
      IF(IBED.EQ.0) GO TO 410
      IF(NBEL(I).EQ.0) GO TO 410
      IF(DARM(I).LE.0) GO TO 410
      IF(I.EQ.1)CDEPP=CDEP(I)
      IF(I.GT.1) CDEPP=(CDEP(I)+CDEP(I-1))/2.0
      T1=STAGE1(I,1)-THBED(I)+CDEPP
      IF(T1.LE.BEDEL ) GO TO 410
      IF(T1.GT.BEDEL ) GO TO 208
      DO 205 K=MIND,N1
205   PTA(I, K)=PTT(I, K)
208   NB=NBEL(I)
      DO 210 L=1,NB
      T1=STAGE1(I,1)-L*THBED(I)+CDEPP
      IF(T1.GT.BEDEL ) GO TO 215
210   CONTINUE
      L=NB
215   DO 260 K=MIND,N1
      ELL=STAGE1(I,1)-THBED(I)*L+CDEPP
      PIN=PTT(I, K)*THBED(I)+PBED(I, K,L)*(ELL-BEDEL )
      L2=L-1
      IF(IBUG.EQ.1) WRITE(6,94) K,L2
94    FORMAT(5X,'K=',I3,2X,'L2=',I6)
      IF(L2.EQ.0) GO TO 255
      DO 245 LA=1,L2
245   PIN=PIN+PBED(I, K,LA)*THBED(I)
255   PTA(I, K)=PIN/DARM(I)
260   CONTINUE
400   CONTINUE
      IF(IBUG.EQ.1) WRITE(6,81) PTA(I, K),I,K
81    FORMAT(5X,'PTA=',F10.6,2X,'I=',I3,2X,'K=',I2)
C
C      COMPUTING FRACTION OF ARMORED AREA
C
      IF(IBED.EQ.1) GO TO 450
410   DO 420 K=MIND,N1
420   PTA(I, K)=PTT(I, K)
```

```
450   CONTINUE
C
C     MODIFICATION OF CARM BY BED-LOAD METHOD
C
      CARM1=CARM
      IF(KARM.EQ.0.OR.KARM.EQ.1) GO TO 460
C
C     CALCULATION OF TOTAL SED. DISCH.
C
      DEP=(RA(I)+RA(I+1))/2.0
      VEL=Q(I)/((BB(I)+BB(I+1))*0.50)/DEP
      A3=ALOG10(DEP/D50(I))
      A12=ALOG10(VEL/SQRT(32.2*1.65*D50(I)))
      USTAR=SQRT(32.2*DEP*S1)
      RS=USTAR*D50(I)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D50(I))
      IF(KARM.GE.4) GO TO 455
      TEMP=USTAR-USC
      IF(TEMP.LE.0.0) TEMP=0.001
      A17=ALOG10(TEMP/SQRT(32.2*1.65*D50(I)))
      QS =10.0**(-2.2786+A12*2.9719+A12*A17*1.0600+A3*A17*0.2989)
      QT=QS*SQRT(32.2*1.65*(D50(I)**3))
C
C     CALCULATION OF BED-LOAD DISCH. (BY SBTM)
C
      A4=ALOG10(S1*1000.0)
      F11=36.0*VIS**2/(32.2*1.65*(D50(I)**3))
      F1=SQRT(2./3.+F11)-SQRT(F11)
      W=F1*SQRT(32.2*1.65*D50(I))
      A6=ALOG10(USTAR/W)
      A10=ALOG10(W*D50(I)/VIS)
      CB=10.0**(-3.7518+A12*2.6279+A4*0.4595+A6*(-2.5055)+
     @ A10*(-0.0932)+A17*0.7395)
      ETAA=(D50(I)*USTAR/USC)/DEP
      F=8.0*32.2*DEP*S1/(VEL**2)
      FN=0.40*SQRT(8.0/F)
      WU=W/USTAR
      CF=1.00
      IF(WU.GT.1.00) CF=1.0/SQRT(WU)
      QB=CB*DEP*VEL*(ETAA**(1./FN+1.))*CF
      QBQT=QB/QT
      PQBQT=QBQT**C1
      CARM1=CARM*PQBQT
C     GO TO 460
455   CONTINUE
C
C     MODIFICATION OF CARM BY DUNE-HEIGHT METHOD
C
      THETA=DEP*S1/(1.65*D50(I))
      THETAC=USC**2/(32.2*1.65*D50(I))
      IF(THETA.LE.1.10) PDH=(1.10-THETA)/(1.10-THETAC)
      IF(THETA.GT.1.10) PDH=(THETA-1.10)/(1.50-1.10)
      IF(PDH.GT.1.00) PDH=1.00
      CARM1=CARM*PDH
      IF(IBUG.EQ.1) WRITE(6,54) THETA,THETAC,PDH,CAR I
54    FORMAT(5X,'THETA=',F6.3,2X,'THETAC=',F6.3,2X,'PDH=',F6.3,
     @ 2X,'CARM1=',F6.3,2X,'I=',I4)
```

```
C
C
460   IF(MIND.GT.N1) GO TO 525
      DO 500 IA=MIND,N1
      IF(KARM.EQ.0.OR.KARM.EQ.2) GO TO 498
      IF(KARM.EQ.4) GO TO 498
C
C     MODIFICATION OF CARM BY GESSLER'S PROBABILITY CURVE
C
      RS=USTAR*D(IA)/VIS
      CALL SHIELD(RS,SHP)
      USC=SQRT(SHP*32.2*1.65*D(IA))
      TCTO=(USC/USTAR)**2
      XX=(TCTO-1.0)/(SQRT(2.0)*0.57)
      PGESS=0.50+0.50*ERF(XX)
      CARM1=CARM*PGESS
      IF(KARM.EQ.1) GO TO 498
      IF(KARM.EQ.3) CARM1=CARM*PGESS*PQBQT
      IF(KARM.EQ.5) CARM1=CARM*PGESS*PDH
498   IF(IBUG.EQ.1) WRITE(6,55) TCTO,PGESS,QBQT,PQBQT,PDH,CAR IT,I,IA
55    FORMAT(5X,'TCTO=',F6.3,2X,'PGESS=',F6.3,2X, 'QBQT=',F6.3,
     1 2X,'PQBQT=',F6.3,2X,'PDH=',F6.3,2X,'CARM1=',F6.3,2X,'IT=',I4,2X,
     2 'I=',I4,2X,'K=',I2)
C
C     CALC. OF ARMOR-COVERED AREA FOR EACH FRACTION
C
      ARM(I,IA)=ARM(I,IA)+CARM1*VOLOUT(I)*(1.0-P(IA))*
     @ PTA(I, IA)/D(IA)
      IF(ARM(I,IA).LT.0.0) ARM(I,IA)=0.0
500   CONTINUE
525   ACF(I)=0.0
      DO 560 IA=1,N1
      IF(IA.LT.MIND) ARM(I,IA)=0.0
      ACF(I)=ACF(I)+ARM(I,IA)
560   CONTINUE
C
      IF(IBUG.EQ.1) WRITE(6,83) I,ACF(I),PTA(I, MIND),PTA(I, N1),
     @ VOLOUT(I)
550   IF(ACF(I).GT.1.00) ACF(I)=1.00
      IF(ACF(I).LT.0.0) ACF(I)=0.0
      IF(IT.EQ.1) GO TO 600
      IF(DARM(I).GE.0.0.AND.ACF(I).EQ.0.0) GO TO 600
C     IF(ACF(I).LT.ACF1(I).AND.KDREJ.EQ.0) ACF(I)=ACF1(I)
600   ACF1(I)=ACF(I)
      IF(IBUG.EQ.1) WRITE(6,82) ACF(I),I
82    FORMAT(5X,'ACF=',F10.4,2X,'I=',I3)
83    FORMAT(5X,'I=',I3,2X,'ACF=',E14.6,2X,'PT(MIND)=',
     @  E14.6,2X,'PT(N1)=',E14.6,2X,'VOLOUT=',E14.6)
C
800   IF(IBLR.EQ.0) GO TO 6000
C
C     CALCULATION OF BED-LAYER SIZE DISTRIBUTION
C
      S1=(SF(I)+SF(I+1))/2.0
      DEP=(RA(I)+RA(I+1))/2.0
      UST=SQRT(32.2*DEP*S1)
      RS=UST*D50(I)/VIS
      CALL SHIELD(RS,SHP)
```

```
      USC=SQRT(SHP*32.2*1.65*D50(I))
      TACL=D50(I)*UST/USC
      VREM=0
      DO 810 K1=1,N1
      T1=TACL*PAC(I,K1)  -TDELD(I, K1)
      IF(T1.LT.0.) T1=0.0
      VREM=VREM+T1
810   CONTINUE
      DO 850 K1=1,N1
      T1=TACL*PAC(I,K1) -TDELD(I, K1)
      IF(T1.LT.0.) T1=0.0
      PAC(I,K1)=(T1+(TACL-VREM)*PT(I, K1))/TACL
      IF(VREM.GT.TACL) PAC(I,K1)=PT(I, K1)
850   CONTINUE
6000  RETURN
      END
C
C
C
C
C     ------------------------------------------
C     SUBROUTINE   HYSORT
C     ------------------------------------------
C
C     THIS SUBROUTINE RECOMPUTES BED-MATERIAL SIZE DISTRIBUTION DUE TO
C     DEGRADATION/AGGRADATION IN EACH TIME PERIOD
C
C     ---------------------------------------------------------
      SUBROUTINE DAHYSO(VOLIN,STAGE1,D50,P,PT,PTT,SSC,CTO,SF,ACF,
     1 RA,BZ,TDELD,VOLOUT,LLIM,DELT,TI,TH,TH1,PTP,EL1,EL2,
     2 PTU,BML,TB,NBEL,THBED,PBED,CDEP,D,D50SL)
C     ---------------------------------------------------------
C
C
C      NOTE: RA IS A PSEUDONYM FOR R
      DIMENSION VOLIN(N,N1),STAGE1(N,MAXMA),D50(NN),P(N1),PT(NN,
     1 N1),PTT(NN,N1),SSC(N,N1),CTO(N),SF(N),ACF(N),
     2 RA(N),BZ(N,N1),TDELD(N,N1),VOLOUT(N),LLIM(N),DELT(N,
     3 N1),TI(N,N1),TH(N),TH1(N),PTP(N,N1),EL1(N),
     4 EL2(N),PTU(N,N1),BML(N),TB(N,N1),NBEL(NN),THBED(NN),
     5 PBED(NN,N1,MAXBED),CDEP(N),D(N1),D50SL(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/WATRES/FFCW,CPPM,FU,IREP,CPREV,FF
      COMMON/SLOHYS/I,K
C
      COMMON/ARM1/IBLR,ISLR,FSLR
      RETURN
C     ************
      ENTRY HYSORT
C     ************
C
C     WARNING:ARMORING FACTOR APPROACHING UNITY
C
      IF (ACF(I).GT.0.98) WRITE (6,2000) ACF(I),I,ITIME,IT
```

```
2000  FORMAT (T5,'WARNING:ARMORING FACTOR =',F5.3,' IN REACH',
     1 I3,' AT TIME',I6,' IT=',I5)
      ACF(I)=AMIN1(0.98,ACF(I))
      NA=(N-1)*100
      IADJ=0
      VOLOUT(I)=0
      TH(I)=0
      TOTAL=0
      LLIM(I)=0
C
      D50R=D50(I)
      IF(ISLR.EQ.1) D50R=D50SL(I)
      DM=(RA(I)+RA(I+1))*0.5
      SM=(SF(I)+SF(I+1))*0.5
      THA=DM*SM/(1.65*D50R   )
      THA=THA*0.333333
C
C      MIXED LAYER THICKNESS COMPUTED BY EQ.6, IIHR 250
C
      TM=DM*(0.079865+2.23897*THA-18.1264*THA**2+70.90*THA**3
     #  -88.3293*THA**2*THA**2)*0.50*FMIX
      DMM=DM*0.1
      IF(TM.LT.DMM) TM=DMM
      FR1=TM/DM
      IF(IBUG.EQ.1) WRITE(6,12) I,TM,DM,FR1
12    FORMAT(5X,'I=',I4,2X,'TM=',E14.6,2X,'DM=',E14.6,2X,'H/D=',F6.3)
C
C     ADJUSTMENT OF SIZE DIST. IF MIXED- LAYER THICKNESS IS
C       MORE THAN THE TOP-LAYER SEDIMENT BED THICKNESS
C
      IF(IBED.EQ.0.OR.IT.GT.1) GO TO 315
      IF(NBEL(I).EQ.0) GO TO 315
      IF(TM.LE.THBED(I)) GO TO 315
      LL=NBEL(I)
      DO 300 L=1,LL
      T1=THBED(I)*L
      IF(TM.GT.T1) GO TO 305
300   CONTINUE
      L=LL
305   L2=L-1
      DO 310 K=1,N1
      PT(I,K)=PT(I,K)*THBED(I)/TM+(TM-THBED(I)*L)/TM*PBED(I,K,L)
      IF(L2.EQ.0) GO TO 310
      DO 306 L1=1,L2
306   PT(I,K)=PT(I,K)+THBED(I)/TM*PBED(I,K,L1)
310   CONTINUE
315   CONTINUE
C
C
      DO 75 K=1,N1
      DELT(I,K)=0
      PTP(I,K)=PT(I,K)
      IF(IT.EQ.1) PTU(I,K)=PT(I,K)
75    TOTAL=TOTAL+TDELD(I,K)
      DO 100 K=1,N1
      TI(I,K)=TM*(1.0-P(K))*PT(I,K)
      TB(I,K)=TI(I,K)*(1.-BETA*FSLR*ACF(I))
70    CONTINUE
```

```
      IF(IBUG.EQ.1) WRITE(6,56) I,K,TB(I,K),TDELD(I,K)
56    FORMAT(/,10X,'TB(',I2,',',I1,',',I2,')=',E14.6,2X,'TDELD=',E14.6)
      TB(I,K)=AMAX1(0.,TB(I,K))
      TH(I)=TH(I)+TB(I,K)
      IF(TDELD(I,K).LT.0.0) GO TO 76
      IF(IADJ.EQ.0) GO TO 72
      IF(IT.EQ.1.AND.TDELD(I,K).GT.TB(I,K)) SSC(I,K)=
     * TB(I,K)/TDELD(I,K)*SSC(I,K)
72    CONTINUE
      IF(IT.EQ.1.AND.TDELD(I,K).GT.TB(I,K)) LLIM(I)=1
      IF(IT.EQ.1.AND.TDELD(I,K).NE.0) DELT(I,K)=IDELT*
     *  TB(I,K)/TDELD(I,K)
      IF(TDELD(I,K).EQ.0) DELT(I,K)=900.0
      DELT(I,K)=AMIN1(DELT(I,K),9000.)
      IF(IT.EQ.1.AND.TDELD(I,K).GT.TB(I,K)) TDELD(I,K)=TB(I,K)
      IF(IT.EQ.1) GO TO 90
      ABC=TH1(I)*PT(I,K)
      IF(IADJ.EQ.0) GO TO 74
      IF(TDELD(I,K).GT.ABC) SSC(I,K)=ABC/TDELD(I,K)*SSC(I,K)
74    CONTINUE
      IF(TDELD(I,K).GT.ABC) LLIM(I)=1
      IF(TDELD(I,K).NE.0) DELT(I,K)=IDELT*ABC/TDELD(I,K)
      DELT(I,K)=AMIN1(DELT(I,K),9000.)
      TDELD(I,K)=AMIN1(TDELD(I,K),ABC)
      IF(TDELD(I,K).GE.0.0) GO TO 90
76    CONTINUE
      DELT(I,K)=AMIN1(DELT(I,K),9000.)
      IF(IT.EQ.1) GO TO 90
      IF(I.LT.NA) TBB=TH1(I+1)*PTP(I+1,K)
      IF(I.EQ.NA) TBB=TH1(I)*PTP(I,K)
90    VOLOUT(I) =VOLOUT(I)+TDELD(I,K)
100   CONTINUE
      IF(IADJ.EQ.0) GO TO 125
      CTO(I)=0.
      DO 120 K=1,N1
120   CTO(I)=CTO(I)+SSC(I,K)
      IF(IBUG.EQ.1) WRITE(6,16) VOLOUT(I),I,J
16    FORMAT(5X,'*** VOLOUT =',E14.7,2X,'I=',I2,2X,'J=',I2)
125   CONTINUE
      IF(VOLOUT(I).LT.0) GO TO 800
      CCC=0
      IF(IT.EQ.1) TH1(I)=TH(I)
      DIN=TH(I)+VOLOUT(I)-TH1(I)
      EL1I=STAGE1(I,1)-TH1(I)
      EL2I=EL1I-DIN
      BEL=BML(I)
      IF(IT.EQ.1) BEL=EL2I
      DO 200 K=1,N1
C
      LINDEX=0
      LDEP=0
      IF(IBED.EQ.1) CALL VSORT(BEL,EL1I,EL2I,DIN,PTT,PT,PTU,VOLIN,
     # NBEL,THBED,PBED,LINDEX,STAGE1,CDEP,LDEP)
C
      IF(LINDEX.EQ.1) GO TO 135
      IF(IT.EQ.1) GO TO 130
      IF(EL2I.GT.EL1I) GO TO 130
      IF(BEL   .GE.EL1I) VOLIN(I,K)=DIN*PTT(I,K)
```

```
      IF(EL1I.GE.BEL   .AND.BEL   .GT.EL2I) VOLIN(I,K)=(EL1I-BEL   )
     #  *PTU(I,K)+(BEL   -EL2I)*PTT(I,K)
      IF(EL2I.GT.BEL   ) VOLIN(I,K)=DIN*PTU(I,K)
130   IF(IT.EQ.1) VOLIN(I,K)=DIN*PTT(I,K)
      IF(EL2I.GT.EL1I) VOLIN(I,K)=DIN*PT(I,K)
135   CONTINUE
      VOLIN(I,K)=AMAX1(VOLIN(I,K),0.0)
      BZ(I,K)= TH1(I)*PT(I,K)-TDELD(I,K)+VOLIN(I,K)
      BZ(I,K)=AMAX1(BZ(I,K),0.0)
200   CCC=CCC+BZ(I,K)
      EL1(I)=EL1I
      EL2(I)=EL2I
      EMIN=EL1I
      IF(EL2I.LT.EL1I) EMIN=EL2I
      BEL=AMIN1(BEL,EMIN)
      TH1(I)=0
      DO 220 K=1,N1
149   TH1(I)=TH1(I)+TB(I,K)
      PT(I,K)=BZ(I,K)/CCC
      IF(I.NE.NA) GO TO 220
      IF(IT.EQ.1) GO TO 220
      IF(BEL.LT.BML(I)) PTU(I,K)=PT(I,K)
      IF(IBUG.EQ.1) WRITE(6,151) I,K,PT(I,K)
151   FORMAT(/,10X,'PT(',I2,',',I1,',',I2,')=',F10.4)
220   CONTINUE
      BML(I)=BEL
      GO TO 900
800   CC1=0
      IF(IT.EQ.1) TH1(I)=TH(I)
      DIN=TH1(I)-VOLOUT(I)-TH (I)
      EL1I=STAGE1(I,1)-TH1(I)
      EL2I=EL1I+DIN
      BEL=BML(I)
      IF(IT.EQ.1) BEL=EL1I
      DO 850 K=1,N1
C
      LINDEX=0
      LDEP=1
      IF(IBED.EQ.1) CALL VSORT(BEL,EL1I,EL2I,DIN,PTT,PT,PTU,VOLIN,
     # NBEL,THBED,PBED,LINDEX,STAGE1,CDEP,LDEP)
C
      IF(LINDEX.EQ.1) VOLIN(I,K)= -VOLIN(I,K)
      IF(LINDEX.EQ.1) GO TO 832
      IF(IT.EQ.1) GO TO 830
      IF(EL2I.GT.EL1I) GO TO 830
      IF(BEL   .GE.EL1I) VOLIN(I,K)=DIN*PTT(I,K)
      IF(EL1I.GE.BEL.AND.BEL.GT.EL2I) VOLIN(I,K)=-((EL1I-BEL)
     #  *PTU(I,K)+(BEL   -EL2I)*PTT(I,K))
      IF(EL2I.GT.BEL   ) VOLIN(I,K)=DIN*PTU(I,K)
830   IF(IT.EQ.1) VOLIN(I,K)=DIN*PTT(I,K)
      IF(EL2I.GT.EL1I) VOLIN(I,K)=DIN*PT(I,K)
832   CONTINUE
      VOLIN(I,K)=AMAX1(VOLIN(I,K),0.0)
      BZ(I,K)=TH1(I)*PT(I,K)-TDELD(I,K)-VOLIN(I,K)
      BZ(I,K)=AMAX1(BZ(I,K),0.0)
850   CC1=CC1+BZ(I,K)
      EL1(I)=EL1I
      EL2(I)=EL2I
```

```
      EMIN=EL1I
      IF(EL2I.LT.EL1I) EMIN=EL2I
      IF(EMIN.LT.BEL) BEL=EMIN
      TH1(I)=0.
      DO 860 K=1,N1
858   TH1(I)=TH1(I)+TB(I,K)
      PT(I,K)=BZ(I,K)/CC1
      IF(I.NE.NA) GO TO 860
      IF(IT.EQ.1) GO TO 860
      IF(BEL.LT.BML(I)) PTU(I,K)=PT(I,K)
860   CONTINUE
      BML(I)=BEL
900   RETURN
      END
C
C     ----------------------------------------------------------
       SUBROUTINE VSORT (BEL,EL1I,EL2I,DIN,PTT,PT,PTU,VOLIN,
     @     NBEL,THBED,PBED,LINDEX,STAGE1,CDEP,LDEP)
C     ----------------------------------------------------------
C
C     THIS SUBROUTINE ADJUSTS MIXED-LAYER COMPOSITION IN CASE OF
C       VERTICAL VARIATION IN SEDIMENT-BED SIZE DISTRIBUTION
C
      DIMENSION PTT(NN,N1),PT(NN,N1),PTU(N,N1),VOLIN(N,N1),
     1 NBEL(NN),THBED(NN),PBED(NN,N1,MAXBED),STAGE1(N,MAXMA),
     2 CDEP(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/INDEX,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/SLOHYS/I,K
C
      IF(NBEL(I).EQ.0) GO TO 1000
      IF(LDEP.EQ.1) DIN= -DIN
      LINDEX=1
      NB=NBEL(I)
      L1=0
      L2=0
      LB=0
      IF(I.EQ.1) CDEPP=CDEP(I)
      IF(I.GT.1) CDEPP=(CDEP(I)+CDEP(I-1))/2.0
      DO 200 L=1,NB
      T1=STAGE1(I,1)-L*THBED(I)+CDEPP
      IF(NB.GT.1) GO TO 50
      IF(T1.GT.EL1I) L1=L
      IF(T1.GT.EL2I) L2=L
      IF(T1.GT.BEL) LB=L
      IF(K.EQ.1.AND.IBUG.EQ.1) WRITE(6,49) I,EL1I,EL2I,BEL,T1
49    FORMAT(5X,'I='I3,2X,'EL1I=',E14.7,2X,'EL2I=',E14.7,2X,
     @ 'BEL=',E14.7,2X,'T1=',E14.7)
50    IF(NB.EQ.1) GO TO 200
      T2=STAGE1(I,1)-(L+1)*THBED(I)+CDEPP
      IF(EL1I.LT.T1.AND.EL1I.GT.T2) L1=L
      IF(EL1I.LT.T1.AND.L.EQ.NB) L1=L
      IF(EL2I.LT.T1.AND.EL2I.GT.T2) L2=L
      IF(EL2I.LT.T1.AND.L.EQ.NB) L2=L
      IF(BEL.LT.T1.AND.BEL.GT.T2) LB=L
```

```
      IF(BEL.LT.T1.AND.L.EQ.NB) LB=L
200   CONTINUE
      IF(L1.GT.0.AND.L2.GE.L1) PTU(I,K)=PBED(I,K,L1)
C
      LL=L2-1
      IF(EL2I.GT.BEL) GO TO 990
      IF(EL2I.GT.EL1I) GO TO 990
      IF(BEL.LT.EL1I) GO TO 250
C     THE CASE FOR BEL GT.EL1I
      IF(L1.EQ.0.AND.L2.EQ.0) VOLIN(I,K)=DIN*PTT(I,K)
      IF(L1.EQ.0.AND.L2.EQ.0) GO TO 250
      IF(L1.GT.0) GO TO 220
      EL1=STAGE1(I,1)-THBED(I)+CDEPP
      EL2=STAGE1(I,1)-L2*THBED(I)+CDEPP
      VIN=(EL1I-EL1)*PTT(I,K)+(EL2-EL2I)*PBED(I,K,L2)
      IF(LL.EQ.0) GO TO 215
      DO 210 LA=1,LL
210   VIN=VIN+THBED(I)*PBED(I,K,LA)
215   VOLIN(I,K)=VIN
220   IF(L1.EQ.0.AND.L2.GT.0) GO TO 250
C
      IF(L1.EQ.L2) VIN=DIN*PBED(I,K,L1)
      IF(L1.EQ.L2) GO TO 235
      EL1=STAGE1(I,1)-THBED(I)*L1+CDEPP
      EL2=STAGE1(I,1)-THBED(I)*L2+CDEPP
      IF(L2.GT.L1) VIN=(EL1I-EL2)*PBED(I,K,L1)+(EL2-EL2I)*
     @  PBED(I,K,L2)
      LM=L1+1
      IF(LL.LT.LM) GO TO 235
      DO 230 LA=LM,LL
230   VIN=VIN+THBED(I)*PBED(I,K,LA)
235   VOLIN(I,K)=VIN
      GO TO 1000
C
250   CONTINUE
C     THE CASE FOR BEL LT. EL1I
      IF(BEL.GT.EL1I) GO TO 1000
      IF(EL2I.GT.BEL) GO TO 990
      IF(L1.EQ.0.AND.L2.EQ.0) VOLIN(I,K)=(EL1I-BEL)*PTU(I,K)+
     @  (BEL-EL2I)*PTT(I,K)
      IF(L1.EQ.0.AND.L2.EQ.0) GO TO 1000
      VIN=(EL1I-BEL)*PTU(I,K)
      EL2=STAGE1(I,1)-L2*THBED(I)+CDEPP
      EL3=STAGE1(I,1)-(LB+1)*THBED(I)+CDEPP
      IF(LB.EQ.L2) VOLIN(I,K)=VIN+(BEL-EL2I)*PBED(I,K,L2)
      IF(LB.EQ.L2) GO TO 1000
C
      LL4=L2-LB
      IF(LL4.EQ.1.AND.LB.EQ.0) VOLIN(I,K)=VIN+(BEL-EL3)*
     1 PTT(I,K)     + (EL3-EL2I)*PBED(I,K,L2)
      IF(IBUG.EQ.1) WRITE(6,252) I,L1,L2,LB,PTU(I,K),PTT(I,K),
     1 PBED(I,K,L2),K
252   FORMAT(5X,'I=',I3,2X,'L1=',I2,2X,'L2=',I2,2X,'LB=',I2,2X,
     1 'PTU=',E14.6,2X,'PTT=',E14.6,2X,'PBED=',E14.6,2X,'K=',I2)
      IF(LL4.EQ.1.AND.LB.EQ.0) GO TO 1000
      IF(LB.GT.0) VIN=VIN+(BEL-EL3)*PBED(I,K,LB)+(EL2-EL2I)*
     @ PBED(I,K,L2)
      LN=LB+1
```

```
      IF(LL.LT.LN) GO TO 400
      DO 260 LA=LN,LL
260   VIN=VIN+THBED(I)*PBED(I,K,LA)
400   VOLIN(I,K)=VIN
      GO TO 1000
C
990   IF(EL2I.GT.BEL) VOLIN(I,K)=DIN*PTU(I,K)
      IF(EL2I.GT.EL1I) VOLIN(I,K)=DIN*PT(I,K)
1000  RETURN
      END
C
C     ------------------------------------------
      SUBROUTINE SHIELD(RS,SHP)
C     ------------------------------------------
C
C     THIS SUBROUTINE APPROXIMATES SHIELD'S CURVE
C
      IF(RS.GE..3.AND.RS.LE.2.0) SHP=.118*(RS**(-.973))
      IF(RS.GT.2.0.AND.RS.LE.4.0) SHP=.090*(RS**(-.585))
      IF(RS.GT.4.0.AND.RS.LE.10.0) SHP=.0434*(RS**(-.119))
      IF(RS.GT.10..AND.RS.LE.30.0) SHP=.0275*(RS**(.0792))
      IF(RS.GT.30..AND.RS.LE.500.) SHP=.0194*(RS**(.181))
      IF(RS.GT.500.0) SHP=.060
      RETURN
      END
C
C     ----------------------------------------------------
       SUBROUTINE TRIB (QTR,QSTR,TDELTR,LOCTR,PTRIB,AC,BC,Q,
     1      LOCBER,BEROS,PBANK,CTO,INPUT)
C     ----------------------------------------------------
C
C     THIS SUBROUTINE COMPUTES THE COTRIBUTION OF TRIBUTARIES
C         AND BANK EROSION
C
      DIMENSION QTR(NTRIB),QSTR(NTRIB),TDELTR(NTRIB,N1),
     1 LOCTR(NTRIB),PTRIB(NTRIB,N1),AC(NTRIB),BC(NTRIB),Q(N),
     2 LOCBER(NBANK),BEROS(NBANK),PBANK(NBANK,N1),CTO(N)
      COMMON/DIMS/N,N1,NT,M1,MAXMA,NN,MEMO,NX,IGR,N1P1,NTONX,NOBS,
     1 NT3651,NT3652,NTRIB,NBANK,IBED,MAXBED,NBED,NTP,NT1,IDREJ,NTY
      COMMON/SCALR/IND¯X,L6,IDELT,VIS,ITIME,GAMA,IFLAG,IT,INDSS,IFLAG1,
     1 ILIMIT,MM1,IEQ,IRES,ISED,ALFA,BETA,C21,C22,FMIX,IFR,IPRINT,
     2IUF,STR,CARM,CPPMUP,IBUG,ICHB,ICOFF
      COMMON/BANK/IBSED,QMIN,IUPS
C
C     IBSED= INDEX VARIABLE FOR INDICATING SIZE DISTR. OF BANK EROSION;
C              IBSED=0 FOR ASSUMING SAME DISTR. AS BED MATERIAL; =1
C              FOR SPECIFYING THEIR VALUES AS INPUT
C     QMIN= MINIMUM WATER DISCHARGE(CFS.) ABOVE WHICH BANK EROSION
C              OCCURS
C     IUPS=INDEX VARIABLE TO SPECIFY UPSTREAM SEDIMENT INFLOW;
C          IUPS=0 FOR CONSTANT SED.CONCN.; =1 FOR FUNCTION
C          OF WATER DISCHARGE
C     NOTE : UPSTREAM SEDIMENT INFLOW IS TREATED IN THE SAME WAY
C     ----            AS FOR TRIBUTARIES
C
       READ(5,10) IUPS
       IF(INDSS.EQ.1.AND.IUPS.EQ.0) READ(5,35) CPPMUP
       WRITE(6,12) IUPS
```

```
      IF(INDSS.EQ.1.AND.IUPS.EQ.0) WRITE(6,17) CPPMUP
      READ(5,10) (LOCTR(I2),I2=1,NTRIB)
      WRITE(6,15)
      WRITE(6,20) (LOCTR(I2),I2=1,NTRIB)
10    FORMAT(12I5)
12    FORMAT(//,10X,'IUPS=',I2,//)
15    FORMAT(//,10X,'TRIBUTARY LOCATIONS (NODE NUMBERS) :',//)
17    FORMAT(/, 5X,'MEAN SEDIMENT CONCN. AT U/S BOUNDARY=',F7.1,
     1 2X,'P.P.M.',/)
20    FORMAT(15X,10I8)
C
22    FORMAT(//,10X,'TRIBUTARY WATER DISCHARGES(CFS.) :',//)
25    FORMAT(6F10.2)
30    FORMAT(15X,10F9.0)
C
C     READ TRIB.SED.DISCH. COEFFICIENTS AC,BC IN QS=AC*Q**BC
C          QS IN TONS/DAY, Q IN CFS.
C
      DO 102 I2=1,NTRIB
      IF(I2.GT.1) GO TO 101
      IF(INDSS.EQ.0) GO TO 102
      IF(IUPS.EQ.0) GO TO 102
101   READ(5,35) (AC(I2),BC(I2))
102   CONTINUE
      WRITE(6,36)
      DO 104 I2=1,NTRIB
      IF(I2.GT.1) GO TO 103
      IF(INDSS.EQ.0) GO TO 104
      IF(IUPS.EQ.0) GO TO 104
103   WRITE(6,40) (AC(I2),BC(I2))
104   CONTINUE
35    FORMAT(2F14.8)
36    FORMAT(//,10X,'SEDIMENT DISCHARGE COEFFICIENTS (FOR TRIBUTARIE',
     @ 'S) :',//)
40    FORMAT(15X,2F14.8)
C
C
C     READ SIZE DISTR. OF TRIB. SED. INFLOWS
C
410   WRITE(6,28)
      DO 500 I2=1,NTRIB
      READ(5,25) (PTRIB(I2,K),K=1,N1)
500   WRITE(6,32) (PTRIB(I2,K),K=1,N1)
28    FORMAT(//,10X,'SIZE DISTRIBUTION OF TRIB. SED. INFLOWS :',//)
32    FORMAT(15X,10F8.3)
C
C     READ PARAMETERS FOR BANK EROSION
C
      IF(NBANK.EQ.0) GO TO 900
      READ(5,61) IBSED,QMIN
      WRITE(6,65) IBSED,QMIN
      READ(5,10) (LOCBER(I3),I3=1,NBANK)
      WRITE(6,70)
      WRITE(6,20) (LOCBER(I3),I3=1,NBANK)
      IF(IBSED.EQ.0) GO TO 700
      WRITE(6,68)
      DO 600 I2=1,NBANK
      READ(5,25) (PBANK(I2,K),K=1,N1)
```

```
600     WRITE(6,32) (PBANK(I2,K),K=1,N1)
700     CONTINUE
61      FORMAT(I5,F10.1)
65      FORMAT(//,10X,'IBSED=',I2,4X,'QMIN=',F10.1,' CFS.',//)
68      FORMAT(//,10X,'SIZE DISTR. OF BANK EROSION :',//)
70      FORMAT(//,10X,'LOCATION OF BANK EROSION (REACH NUMBER) :',//)
C
C       READ BANK EROSION RATE,BEROS (IN CFT./MILE/DAY)
C
        READ(5,25) (BEROS(I3),I3=1,NBANK)
        WRITE(6,72)
        WRITE(6,74) (BEROS(I3),I3=1,NBANK)
72      FORMAT(//,10X,'BANK EROSION COEFFICIENT (CFT/MILE/DAY) :',//)
74      FORMAT(15X,8F10.1)
900     CONTINUE
        RETURN
C     *********************************
        ENTRY TRIBQS
C     *********************************
C       TRIBQS CALLED AT BEGINNING OF EACH TIME STEP TO LOAD
C       QSTR, TRIBUTARY SEDIMENT INFLOWS
C
C       COMPUTING SED.DISCH. OF TRIBUTARIES
C
        DO 400 I2=1,NTRIB
        IF(I2.GT.1) GO TO 240
        I=LOCTR(I2)
        IF(INDSS.EQ.1.AND.IUPS.EQ.0) CTO(I)=CPPMUP/(2.65E6)
240     CONTINUE
        IF(I2.GT.1) GO TO 250
        IF(INDSS.EQ.0) GO TO 300
        IF(INDSS.EQ.1.AND.IUPS.EQ.0) QSTR(I2)=CPPMUP/2.65E6
      @ *QTR(I2)
        IF(INDSS.EQ.1.AND.IUPS.EQ.0) GO TO 300
250     QSTR(I2)=AC(I2)*QTR(I2)**(BC(I2))*2000.0/(62.5*86400.0)
        IF(I2.GT.1) GO TO 300
        I=LOCTR(I2)
        IF(INDSS.EQ.1.AND.IUPS.EQ.1) CTO(I)=QSTR(I2)/QTR(I2)
300     CONTINUE
400     CONTINUE
        IF (IBUG.NE.0) WRITE (6,2000) (QSTR(I2),I2=1,NTRIB)
2000    FORMAT (9X,'TRIBUTARY SEDIMENT LOADS:',(T35,12F8.2))
        RETURN
        END
C
C     ---------------------------------------------------------
      SUBROUTINE ERROR1(IEND,MEMO,N,M1,N1,NT,MAXMA,NOBS,NX,IGR)
C     ---------------------------------------------------------
C
      IERR=1
      WRITE(6,2000) IERR
2000  FORMAT(/,1X,110(1H*),' ERROR',I2)
      WRITE(6,2001) IEND,MEMO,N,M1,N1,NT,MAXMA,NOBS,NX,IGR
2001  FORMAT(T20,'REQUIRED MEMORY=',I7,' (WORDS) EXCEEDS DIMENSION ',
     1 'OF ARRAY T(',I7,')',/,T20,'N,M1,N1,NT,MAXMA,NOBS,NX,',
     2 'IGR=:',8I5)
      STOP
C
```

```
      ENTRY ERROR2(I,MM,MAXMA)
      IERR=2
      WRITE(6,2000) IERR
      WRITE(6,2002) I,MM,MAXMA
2002  FORMAT(T20,'SECTION',I3,':NO. OF DEFINITION LEVELS',I3,
     1 ' EXCEEDS MAXIMUM ALLOTTED ,MAXMA=',I4)
      STOP
C     ************
      ENTRY ERROR3(IT,ITIME,TEMPF,TFLAST)
C     ************
      IERR=3
      WRITE (6,2000) IERR
      WRITE (6,2003) TEMPF,TFLAST,IT,ITIME
2003  FORMAT (T20,'WATER TEMPERATURE=',F10.3,' EXCEEDS MAXIMUM
     1        ALLOWED=',F10.3,' IT=',I5,' ITIME=',I5)
      RETURN
C     ************
      ENTRY ERROR4(I,IT,ITIME,ITER,DEL)
C     ************
      IERR=4
      WRITE (6,2000) IERR
      WRITE (6,2004) ITER,I,IT,ITIME,DEL
2004  FORMAT (T20,'BACKWATER ITERATIONS XCEEED',I4,'SECTION',I4,
     1        ' IT=',I4,' ITIME=',I4,' DELTA =',F10.3)
      RETURN
C     ************
      ENTRY ERROR5(I,IT,ITIME,IT2,TT)
C     ************
      IERR=5
      WRITE (6,2000) IERR
      WRITE (6,2005) IT2,I,IT,ITIME,TT
2005  FORMAT (T20,'TLTM ITERATIONS EXCEED',I4,' SECTION',I4,'IT=',
     1        I4,' ITIME=',I4,' TT=',F10.3)
      RETURN
      END
```

APPENDIX C

Sample Input for Run R2

```
//GO.SYSIN DD *
   DEGRADATION D/S OF GAVINS POINT DAM (1956-76)
   22     1     8   012    02     0     0     0     7     6     0     0
    0    00     0    12
    0     0     0   061     0     0     1     0     0     0     0    00
    1     1     1     0     1     5     1     0
 1.00        1.00        1.00        1.00        1.00       1.90
 0.0001890        523.0
    0
   0.0
   22    21    19    14     8     7     4
0.002652         1.5790
0.002652         1.5790
0.001360         1.6700
```

```
0.0002649        2.1220
0.0001963        2.8553
0.00002854       2.6633
0.0          0.0          0.0         0.          0.          0.
0.           0.
.39          .433          .127        .05         0.           0.
0.           0.
.39          .433          .127        .05         0.           0.
0.           0.
.39          .433          .127        .05         0.           0.
0.            0.
.65           .284         .066         0.          0.           0.
0.            0.
.65           .284         .066         0.          0.           0.
0.            0.
1.00          0.           0.           0.          0.           0.
0.            0.
    0   30000.0
   21    20    19    18    17    16
657.         657.         1170.        1170.       1732.       1732.
.062          .149         .297        .590        1.19        2.4
4.80          9.52         19.1
    606.15            2                         SECTION NO.  1
   947.500                                600.000
   997.500                                600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    615.90            2                         SECTION NO.  2
   954.96                                 600.000
  1004.96                                 600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    625.65            2                         SECTION NO.  3
   962.43                                 600.000
  1012.43                                 600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    635.40            2                         SECTION NO.  4
   973.85                                 600.000
  1023.85                                 600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    645.15            2                         SECTION NO.  5
   985.28                                 600.000
  1035.28                                 600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    654.90            2                         SECTION NO.  6
   994.39                                 600.000
  1044.39                                 600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    664.65            2                         SECTION NO.  7
  1003.50                                 600.000
  1053.50                                 600.000
    0.0          0.1050       0.5000       0.8500      0.9350      0.9700
    1.0000       1.0000       1.0000
    674.40            2                         SECTION NO.  8
```

1013.03			600.000		
1063.03			600.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
1.0000	1.0000	1.0000			
684.15	2			SECTION NO.	9
1024.10			600.000		
1074.10			600.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
1.0000	1.0000	1.0000			
693.90	2			SECTION NO.	10
1033.22			600.000		
1083.22			600.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
1.0000	1.0000	1.0000			
703.65	2			SECTION NO.	11
1042.32			625.000		
1092.32			625.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
1.0000	1.0000	1.0000			
713.40	2			SECTION NO.	12
1053.03			650.000		
1103.03			650.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
1.0000	1.0000	1.0000			
723.15	2			SECTION NO.	13
1063.74			675.000		
1113.74			675.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
1.0000	1.0000	1.0000			
732.90	2			SECTION NO.	14
1073.11			700.000		
1123.11			700.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
0.997	1.0000	1.0000			
742.65	2			SECTION NO.	15
1082.48			725.000		
1132.48			725.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
0.9970	1.0000	1.0000			
752.40	2			SECTION NO.	16
1093.39			750.000		
1143.39			750.000		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
0.9970	1.0000	1.0000			
762.15	2			SECTION NO.	17
1104.30			1020.00		
1154.30			1020.00		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
0.9970	1.0000	1.0000			
771.90	2			SECTION NO.	18
1115.22			1280.00		
1165.22			1280.00		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700
0.9970	1.0000	1.0000			
781.65	2			SECTION NO.	19
1126.13			1540.00		
1176.13			1540.00		
0.0	0.1050	0.5000	0.8500	0.9350	0.9700

```
    0.9970     1.0000     1.0000
    791.40          2                        SECTION NO. 20
  1137.87                          1800.00
  1187.87                          1800.00
    0.0        0.1050     0.5000    0.8500     0.9350     0.9700
    0.9970     1.0000     1.0000
    801.15          2                        SECTION NO. 21
  1149.61                          1540.00
  1199.61                          1540.00
    0.0        0.1050     0.5000    0.8500     0.9350     0.9700
    0.9890     0.9940     1.0000
    810.90          2                        SECTION NO. 22
  1161.34                          1800.00
  1211.34                          1800.00
    0     0
    1     2  1000.        1     0     5     0.50
     0 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
     1 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
   120 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
   121 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
   240 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
   241 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
   360 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
   361 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
   480 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
   481 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
   600 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
   601 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
   720 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
   721 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
   840 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
   841 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
   960 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
   961 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  1080 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  1081 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  1200 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  1201 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  1320 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  1321 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  1440 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  1441 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  1560 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  1561 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  1680 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  1681 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  1800 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  1801 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  1920 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  1921 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  2040 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  2041 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  2160 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
  2161 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  2280 70.36000.00   776.00   240.00 2016.00 1992.00   248.00   590.00   961.97      0.0
  2281 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  2400 70.36000.00   192.00    60.00  504.00  498.00    62.00   147.00   961.97      0.0
  2401 38.15000.00   192.00    60.00  504.00  498.00    62.00   147.00   955.56      0.0
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2520	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
2521	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
2640	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
2641	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
2760	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
2761	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
2880	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
2881	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
3000	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
3001	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
3120	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
3121	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
3240	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
3241	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
3360	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
3361	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
3480	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
3481	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
3600	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
3601	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
3720	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
3721	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
3840	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
3841	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
3960	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
3961	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
4080	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
4081	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
4200	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
4201	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
4320	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
4321	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
4440	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
4441	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
4560	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
4561	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
4680	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
4681	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
4800	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
4801	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
4920	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
4921	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
5040	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
5041	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
5160	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
5161	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
5280	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
5281	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
5400	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
5401	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
5520	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
5521	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
5640	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
5641	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
5760	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
5761	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
5880	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
5881	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0

6000	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
6001	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
6120	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
6121	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
6240	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
6241	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
6360	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
6361	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
6480	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
6481	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
6600	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
6601	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
6720	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
6721	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
6840	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
6841	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
6960	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
6961	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
7080	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0
7081	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
7200	38.15000.00	192.00	60.00	504.00	498.00	62.00	147.00	955.56	0.0
7201	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
7320	70.36000.00	776.00	240.00	2016.00	1992.00	248.00	590.00	961.97	0.0
7321	70.36000.00	192.00	60.00	504.00	498.00	62.00	147.00	961.97	0.0

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